N. Ibrahim

N. Ibrahim 9.12.29

EGYPTIAN GOVERNMENT.

Ministry of Public Works.

THE PROBLEM OF THE UPPER NILE.

By

F. NEWHOUSE, B. Sc., M. Inst. C.E.
Director of the Sudan Projects and Designs Office.

3rd EDITION.

CAIRO.
GOVERNMENT PRESS.
1929.

EGYPTIAN GOVERNMENT.

Ministry of Public Works.

THE PROBLEM OF THE UPPER NILE.

By

F. NEWHOUSE, B. Sc., M. Inst. C.E.
Director of the Sudan Projects and Designs Office.

3rd EDITION.

CAIRO,
GOVERNMENT PRESS,
1929.

PREFACE TO THIRD EDITION.

Criticism of this note has been directed to two points: the question of the time of travel of water from Mongalla to Malakal and the fact that evaporation on the probable area of the Bahr el Gebel swamps accounts for only a small proportion of the total losses on this river.

There is some misconception about the phrase " time of travel " as applied to the motion of water in a channel. The time refers not to the motion of individual particles of water but to the interval between the occurrence of a change of discharge at an upstream site and the occurrence of the maximum effect of this change at a downstream site. The discharge of the Bahr el Gebel as at Malakal—the Malakal swamps discharge—is in time and magnitude the result of the interaction of the Mongalla discharge, the evaporation and rainfall on the swamps between Mongalla and Malakal and the levels of the River Sobat at its mouth, the most important cause being the Mongalla discharge.

Under present circumstances a marked rise of the river at Mongalla appears at the tail end of the swamps several months later. The actual time in any one year is difficult to determine very accurately owing to the very slow variation and small range of the Malakal swamps discharge, which may cause any small error to displace the occurrence of the maximum or minimum disproportionately. There can however be no doubt that the average magnitude of the effect is of the order of 3 to 4 months, as deduced from table VIII in the note.

It is stated in the note that the mean area of the swamps (on the Bahr el Gebel) is about 5000 square kilometres and the net annual evaporation minus rainfall is shown in table XI to be about 60 cms.

Measurements of the area of the swamps at different levels do not exist, nor can the swamp limit be defined except within very wide limits. We know the swamps are about 500 kilometres long and it is thought that their average width in a normal year at mean levels is about 10 kilometres which gives a mean area of 5,000 square kilometres. The actual mean evaporation area properly weighted according to the net monthly evaporation and the wetted area in that month is not known, but as the maximum evaporation occurs in the spring and early summer, when the swamps are at their lowest, it may very well be of the order of 5,000 square kilometres.

The order of the figure for evaporation has been confirmed by another year's measurements, so that the facts as known at present stand that evaporation on the Bahr el Gebel Swamps appears to account only for about 3 milliard cubic metres out of the Swamps losses of 13 milliards.

Even if the area has been underestimated by 100 per cent and should be 10,000 square kilometres instead of 5,000, we can only account for six milliards out of 13. Where the rest goes to, is not known.

The geography of the country between the Bahr el Gebel and the River Sobat is fairly well known and it is highly improbable that any of the Bahr el Gebel water escapes this way. On the other hand, very little is known of the country to the west of the Bahr el Gebel Swamps while the so-called Gebel-Ghazal ridge or watershed is little more than a series of mounds. It may be that the Gebel water can escape in large quantities, at high levels, into the Ghazal Swamps and be lost there.

Another possibility is that large quantities are absorbed into the sub-soil which is known to be running sand over considerable areas of the swamps.

The chief object of the note was to state the facts, as we know them, about the Sudd problem and to enumerate the geographic, hydrologic and physical data which are still required to enable the problem to be solved. Further investigation of the " time of travel " from Mongalla to Malakal and the location of the lost water are among the numerous puzzles still to be solved for all we can say definitely about the Upper Nile is that about 13 milliard metres cube of water are lost annually between Mongalla and Malakal and we do not know where they go.

If the hypothesis is true that about 7 to 10 milliards escape into the Ghazal Swamps, then the Pharaonic Project (Chapter VI) would yield far larger quantities of water than one milliard metres cube annually, while its cost would not increase.

It is again to be emphasized that the chief object of this note is to show how much investigation is still needed in connection with the Sudd problem.

F. Newhouse,

Director, Sudan Projects and Designs Office.

February 1929.

PREFACE TO SECOND EDITION.

The only change in this edition is the correction of some misprints and of an arithmetical error on page 49 in the calculations regarding the disposal of Torrents in an average year.

July 1928.

PREFACE TO FIRST EDITION.

The data of discharges, gauges, etc., used in this work have been supplied by the Physical Department of the Egyptian Government.

The author is much indebted to Dr. H. E. Hurst, the Director General of that Department, for many illuminating discussions and suggestions in connection with the hydrology of the Upper Nile.

April 1928.

INDEX.

LIST OF TABLES.

LIST OF MAPS AND DIAGRAMS.

LIST OF BOOKS.

Report upon the Basin of the Upper Nile.
by Sir. W. Garstin, E.G. Press, 1904.

Physiography of the River Nile and its Basin.
by Col. Sir H.G. Lyons, E.G. Press, 1906.

Nile Control.
by Sir M. MacDonald, 2nd. Edition, E.G. Press, 1921.

Report of the Mission to Lake Tana.
by Mr. G.W. Grabham, & Mr. R.P. Black, E.G. Press, 1925.

Lake Plateau Basin of the Nile. (two parts).
by Dr. H.E. Hurst, E.G. Press, 1925 and 1927.

Summary of Hydrographic Data in the Southern Sudan to End of 1923.
by Mr. F. Newhouse, E.G. Press, 1926.

MINISTRY OF PUBLIC WORKS, EGYPT.

THE PROBLEM OF THE UPPER NILE.

INTRODUCTION AND SUMMARY.

This note has been written primarily to show what information is still needed to enable a project to be prepared that will make available for beneficial use in irrigation in Egypt and the Sudan the largest possible proportion of the water at present flowing in the Basin of the Nile below Lake Albert. The main lines of such a project were indicated by Sir Murdoch MacDonald in "Nile Control" in 1920 and received the approval of the Nile Projects Commission, and the investigations that have been proceeding ever since that date have shown that the proposed solution was the right one, but that the works needed for a complete control of the Nile in the interests of irrigation on its banks will have to be even more extensive than were then contemplated, if the desired goal of the complete development of Egypt is to be attained, with a concomitant extension of irrigation in the Sudan.

The source of the Nile is at the head of the River Kagera, over 6,500 kilometres from the Sea. This river enters Lake Victoria on its western shore and the Victoria Nile flows out of this lake at the North end over the Ripon Falls, on through swampy Lake Kioga, over falls again and so enters Lake Albert at its northern end. The Albert Nile issues from this Lake at a distance of only 3 or 4 kilometres and flows in a swampy channel to Nimule, the Sudan frontier, which is the first place where the river is regularly measured.

Our knowledge of its hydrology above this point is based on a few scattered discharge observations and inadequate observations of rainfall and lake gauges, but from Nimule onwards there are numerous gauges regularly recorded and less frequent, (and still too few) sites where discharges are regularly observed. Such discharge stations were first started on the Upper Nile in 1922 and have been gradually increased in number, but of course the period during which the observations have been taken is not yet long enough to give reliable mean values.

After Nimule the river, now known as the Bahr el Gebel, plunges over the Fola Cataract and numerous other rapids to Rejaf, from whence it is navigable all the way to Khartoum.

On the reach between Lake Albert and Rejaf numerous streams join the river which are all torrents, being mostly quite dry in summer though a few have a small flow at that season but carrying a heavy discharge in flood. What proportion their contribution bears to the total flow in the river can only be estimated approximately owing to the absence of exact knowledge of the discharge leaving Lake Albert, but the fact that their flow so far from being negligible is of considerable importance is one of the main points that has been brought to light in the last few years. The river is regularly measured at Mongalla some distance below Rejaf, as after Mongalla no more tributaries are known definitely to join it for over 700 kilometres.

After Rejaf the river flows in a valley that becomes more and more swampy till beyond Bor the real swamps of the Upper Nile are entered, known as the Sudd Region. The area of these swamps is on the average probably about 5,000 square kilometres, but varies with the level. They contain two fairly large islands—solid land which is dry at low water—but there are only three or four little patches of land which are dry at all stages of the river level. The main channel of the river became completely closed by "Sudds" of floating vegetation during the Mahdi's rebellion and the first step taken by the Egyptian Government after the Reconquest was the removal of these Sudd blocks, which are however still liable to recur. The Bahr el Gebel now flows through the Swamps in one main stream with many side channels leaving and rejoining it, so that its section and discharge are continually varying. In the lower 300 kilometres one of these side branches becomes a definite separate stream, the Bahr el Zeraf, and trends away from the Bahr el Gebel in its own valley, being for the latter part of its course a clearly defined stream running through solid land.

The Swamps end at Lake No where the Bahr el Ghazal joins the Bahr el Gebel to form the White Nile, the Bahr el Zeraf entering the latter river some way further on. Such water as issues from the Swamps does so through the Bahr el Gebel and Bahr el Zeraf, but nearly half the amount passing Mongalla has been lost in the Swamps, amounting on the average to over thirteen milliards of cubic metres annually. How to prevent this loss and make the water saved available for irrigation in Egypt in accordance with the seasonal requirements of cultivation is the problem of the Upper Nile.

The Bahr el Ghazal drains a very large area with a heavy rainfall, but the country is mostly very flat and the swamps extensive so that the present contribution of this river to Egypt's water supply is negligible. From Lake No the White Nile flows in a wide shallow valley with swampy berms and islands to the confluence of the River Sobat being joined before then by the Bahr el Zeraf. The River Sobat is the main tributary of the White Nile, providing about half its annual discharge at this point, and though its discharge near the mouth has been measured regularly for many years very little is known of the hydrology of its upper reaches. It is formed by the junction of the Rivers Baro and Pibor, the latter having many small tributaries and flowing out of extensive swamps.

The discharge of the River Baro is known to suffer heavy losses in the Autumn and thus offers possibilities of increasing Egypt's water supply by stopping these losses, whose size is however much smaller than that of the losses in the Bahr el Gebel swamps, being probably of the order of one milliard cubic metres per annum.

After the River Sobat mouth the channel of the White Nile becomes less swampy, though very wide and shallow, until it enters what may be called the desert reach near Kosti. A little above Kosti is the rocky hill, Gebelein, with rock outcrops in the river bed in the vicinity, which forms a possible site for a dam to make a reservoir of about one milliard cubic metres capacity. From Kosti onwards the river is still very wide and shallow but swamp has quite disappeared and the banks are flat sandy beaches. This reach forms a natural reservoir, as the slope of the river here is very flat and the Blue Nile, which joins the White Nile at Khartoum to form the Main Nile, has a steep slope and rises very rapidly in flood, the effect being to dam up the water of the White Nile and form a pond of still water in the valley of this river extending for over 200 kilometres from the junction. At 47 kilos. above Khartoum on the White Nile is situated Gebel Aulia where the construction of a dam is projected by the Egyptian Government to take advantage of the natural features of the White Nile valley by turning it into a large reservoir.

The Blue Nile rises at Lake Tana in Abyssinia though only a small part of its water comes from the Lake, most coming from large perennial tributaries of which two, the Rahad and the Dinder, join it within the Sudan frontier. The construction of a dam at Lake Tana is included among the projects proposed for obtaining complete control of the Nile.

The Main Nile has only one tributary, the River Atbara, which joins it about 300 kilos. below Khartoum and after its confluence the River flows on without further addition to Egypt and through the Rosetta and Damietta branches to the Sea. The Blue Nile and Atbara are rivers whose flow varies very greatly in quantity during each year, the latter having none at all in the summer, and moreover, while the low water supply is clean and free of silt, the flood waters are heavily laden with the rich silt that has formed Egypt.

The consequence of this is that the velocity of the current of these rivers must not be checked by dams in full flood, for heavy deposits of silt would choke the reservoirs formed, but the water of the White Nile having been filtered by its long slow passage through the Swamps is practically free of silt and therefore a dam built on that river can operate at any season. The importance of this point is very great and constitutes the chief value of Gebel Aulia on the White Nile as a reservoir site.

To return to the Sudd Region: in general terms we are dealing with a large volume of water pouring out of Lake Albert and from torrents in gradually increasing quantity into a river bed in which water is flowing at a low level, first between wide berms that will become swamps and then through large areas of swamp in a state of greater or less dryness. As the flow increases the berms get covered and the swamps increase in size absorbing large quantities of water first in filling and then in evaporation from the large water and swamp surfaces formed. The total quantity of water passing Mongalla and

that issuing from the Swamps is known with considerable accuracy for recent years and to a reasonable approximation for the earlier ones, and the time of travel has also been calculated and found to be on the average 3½ months. This does not agree with the fact that there is a very close relationship between the Mongalla and Malakal discharges at a six months' interval at certain seasons, and therefore indicates the necessity for further research on this important point.

Egypt's water requirements when fully developed are calculated from statistics of the water actually used in Lower Egypt at the present time, and are found to be of the order of sixty two milliard cubic metres per annum at Aswân including the needs of navigation.

This is of the same order as the figure given by the Nile Projects Commission and some 20 per cent higher than the figure adopted by Sir M. MacDonald in 1920. The Sudan's requirements, at the period when Egypt is fully developed, are still assumed to be six milliard cubic metres per annum, the figure given by Sir M. MacDonald, thus bringing the total requirements of Egypt and the Sudan, by the time the former is fully developed, to sixty eight milliard cubic metres per annum.

The average discharge of the Nile at Aswân is about eighty-two milliard cubic metres per annum, falling with fair frequency to sixty-eight milliards and exceptionally, as in 1913–1914, to forty-two milliards. It would therefore seem that there is practically always enough water in the river to provide for the above needs, if it is properly conserved and distributed. This view however does not allow for the fact that over half this discharge comes in the three flood months and is then far in excess of requirements and is, for a large part of the time, so laden with silt that what cannot be used directly must be allowed to flow on to the sea unchecked in reservoirs. The amount so wasted can be reduced by stopping the flow of the White Nile in flood before it joins the Main Nile, for this river—as already explained—is practically silt free, and by stopping the clear portion of the flow of the Blue Nile before it enters that river. The first can be done by a dam at Gebel Aulia on the White Nile and the second by a dam at the outlet of the Blue Nile from Lake Tana. Even after this has been done the waste to sea is still very large and the water available for Egypt after allowing for this waste and the inevitable evaporation losses in reservoirs much less than is required. It therefore becomes necessary to stop any waste there may be in the Nile basin, the chief being the enormous annual losses in the Sudd Region of the Upper Nile.

This waste can be stopped and a great part of the water saved made available for use in Egypt by the construction of a reservoir at Lake Albert in which to store the water till it is wanted and a canal or a canalised river through or round the Sudd Region in which the water can be led without abnormal losses to the White Nile and on to Egypt. It has only of recent years been discovered that a large proportion of the water that enters the Sudd does not come out of Lake Albert but from rivers and torrents below the Lake so that a dam at Lake Albert will have less water to store than was once estimated. This complicates the problem of dealing with the Sudd waste, and a further complication is added by the necessity of providing for navigation on the Bahr el Gebel all through the year, thus making it impossible ever to close Lake Albert Dam completely and causing the need for a reservoir lower down where the navigation water and the Torrential flow can both be conserved, for a great part of them would arrive in Egypt coincidently with the flood and therefore be wasted. These waters must therefore be stopped from entering the Main Nile during flood which can only be done on the White Nile, and it is calculated that if this is done, allowing for ordinary transmission losses and evaporation losses in reservoirs, on the average about 35 per cent to 40 per cent of the present Sudd waste could be made available for use in Egypt.

These considerations point out the need for a revision of the idea that turning Lake Albert into a reservoir would provide final and sufficient storage in the Nile Basin, for even after everything possible has been done by making a Sudd Channel and Lake Albert Dam, a large reservoir at Gebel Aulia, Lake Tana Dam, and heightening Aswân Dam to catch the later stages of the flood supply, there would still only be about 63 milliard cubic metres per annum available on the average to meet needs of about 68 milliards. Egypt can therefore not develop to its fullest extent, with concomitant development in

the Sudan, without going beyond the present sources of supply to increase the water entering the Nile below Lake Albert either by works on Lake Victoria and the Victoria Nile, by control of the River Baro or the conservation and control of the Bahr el Ghazal system of rivers, if investigation should show that such projects would be feasible, which seems to be improbable as regards Lake Victoria.

If this is not done then during a typical series of fifteen years such as 1912–1926, in eight of them Egypt would have been short even of the sixty-three milliards that the system can provide on the average, and this after making full use of the possibilities of over-year storage in Lake Albert, by holding up the excess in years of very good supply and using it in subsequent years. The maximum amount thus accumulated would have been about thirty-two milliards of cubic metres and to provide fully against such a series of years about forty-nine milliards of cubic metres are required, hence the capacity of the reservoir at Lake Albert should be of the order of fifty milliard cubic metres involving a command of about ten metres range of levels on the Lake, which has an area of about 5,300 square kilometres.

The development of the River Baro and the Bahr el Ghazal may produce extra water in the White Nile at a time when there is already too much in Egypt and therefore require storing. It is for the future to say whether the capacity of Gebel Aulia is large enough for this purpose, or whether a reservoir at Gebelein will be required in addition.

The effect of cutting the Sudd Channel will be to lead the navigation water and the torrents to Egypt in flood except in so far as they can be stopped at Gebel Aulia or diverted into the swamps. For many years in succession their amount will be such as to need conservation in Gebel Aulia and none will be escaped, with the consequence that the Sudd Region will inevitably be reclaimed. Every ten years or so however there may be a large flood and the question will then arise as to whether the excess waters are to be escaped into, and flood out, the Sudd Region again or passed on to Gebel Aulia and allowed to flood the high lying plains of the White Nile Province for a short period. A possible alternative is to pass the excess down the Sudd Channel and escape it at its lower end into the northern section of the Sudd, the Lake No Swamps. The choice among these alternatives will have to be made some day and this fact must have an important bearing on the design of the series of works for controlling the Upper Nile. It seems clear that a large reservoir is required on the lower reaches of the White Nile, not only to stop and conserve for use in summer as large a proportion as possible of the present flood discharge of the White Nile, but to catch the navigation waters and torrents in the future in years of low and average supply and possibly to stop dangerous excess supplies reaching Egypt in years of high flood.

The possibility has to be considered whether either Lake Albert Dam alone or the Sudd Channel alone can serve Egypt, but no definite answer can yet be given on this point for lack of the necessary data, hydrologic and geographic. The possibility cannot be excluded that Lake Albert Dam alone might do some good in all years, but the Sudd Channel alone could not do so always, though it might sometimes. It seems clear however that the utility of either work without the other is very limited.

Two sites for Lake Albert Dam have been suggested one at Pakwatch, fifteen kilos. from Lake Albert and one at Nimule, 216 kilos. from the Lake. To prepare the Lake Albert Dam project much survey and hydrological work is required, including a survey of the above two sites and a reconnaissance of the valley between them, but the most important thing is the regular measurement of the Lake Albert discharge. Several years' observations are necessary to acquire sufficient data, so their inception is a matter of urgency.

There are in all nine alternative proposals for the line of the Sudd Channel, which can be divided into two groups, the first containing those projects which propose a new channel for all or part of the way and the second those that propose to develop and remodel existing waterways. The possibility of making some use of the existing waterways to the limit of their capacity without remodelling is envisaged by most of the projects of Group 1.

Each group has obvious advantages and disadvantages, the first group involving less total excavation but requiring a long time before the first benefit is felt by Egypt, while for the second group it is claimed that an early gradual increase of Egypt's water supply can

easily be obtained, even though the total final cost may be greater, but the necessary surveys and hydrologic observations which would enable the total cost and the possibilities of each proposal to be worked out and compared are still lacking to a very great extent.

While both surveys and hydrology are important the latter should take precedence, for the value of a series of observations increases very fast with its length, while survey can be done at any time and, within limits, at any speed.

As it may yet take many years before the necessary data are accumulated and the calculations made that will enable the best project to be chosen, and as it is desirable to obtain some increase in Egypt's water supply from these sources at an early date, a provisional or false work called the " Pharaonic Project " is suggested for construction which is such as not to prejudice the selection of one of the above alternatives and might provide in a few years a milliard of cubic metres per annum at a cost of about L.E. 1,000,000.

Though some years study may still be required before definitely choosing the line of the Sudd Channel, yet the nature of the work required above and below the Sudd Region proper is fairly clearly definable even now, so that as soon as necessary excavating machinery is available a beginning could be made with work that is certainly required, though by itself it might not produce any great increase in water supply.

The question of masonry works has only been touched on incidentally. They will include the Lake Albert Dam and Bor Barrage and possibly a Sudd with lock on the White Nile above the Sudd Channel mouth, while the canal itself will probably have to have numerous regulators with locks and escapes.

No special investigations are required for these apart from the surveys etc. already specified as being necessary to work out the best channel line, for these will produce the data needed to design the masonry works.

The present water supply of Egypt is insufficient for her expanding population and even when the colossal series of works described in this Note is completed there will still be need for more water, so not only should the investigations required to complete their design be pressed forward, but the search for, and investigation of, other sources of supply must be begun.

CHAPTER I.

HISTORICAL AND DESCRIPTIVE.

Historical.

The River Nile and its sources have been since the earliest historical times a mystery to civilised man and the search for them a constant theme of romance and adventure till they were discovered by Grant, Speke, and Baker in the 19th century.

The Nile is " The River which is Egypt " and the Government of the country has always realised its supreme importance and supported all efforts to solve its problems. Baker, who discovered Lake Albert, was a servant of the Government of Egypt and the work of exploration and hydrologic studies was continued by General Gordon and his staff, as also by various explorers of whom the chief were Emin Pasha and Schweinfurth. The Mahdist rebellion in the Sudan naturally put a stop to all such work, but as soon as possible after the Reconquest in 1898 the Egyptian Government delegated Sir William Garstin, Under Secretary of State for Public Works, to visit the Upper Nile and report on the feasibility of increasing Egypt's water supply by training works in the Southern Sudan. Sir William Garstin made several long tours, not only in the Sudan but in the region of the Great Lakes, and published a first report in 1901 and a subsequent one in 1904.

The latter report " The Basin of the Upper Nile " is a monumental work and laid the foundations for all the studies and projects since carried out by the Egyptian and Sudan Governments in the Sudan. The first consequence of his report was the formation in 1904 of the Sudan Irrigation Service as a branch of the Egyptian Government Irrigation Service. The duties of this Service were to study and prepare projects for developing irrigation in Egypt and the Sudan. This note does not deal with the part of the work that concerned projects in the Sudan (Gezira, Kassala, Main Nile basins etc.) but only with the studies and projects on the Upper White Nile and its branches, which were undertaken for the purpose of increasing Egypt's water supply. The question of a dam on the White Nile (Gebel Aulia) for forming a reservoir of summer water for Egypt is also only discussed incidentally.

Lake Victoria and the Victoria Nile.

The Nile rises in the Lake Plateau of East Central Africa and flows to the Mediterranean Sea. Its basin covers about 2,900,000 square kilometres, roughly one-third of the size of Europe, but large parts of this contribute practically nothing to its water supply, while the basin also contains extensive swamps which, through evaporation, reduce the amount of water that should flow into the river.

Our knowledge of the hydrology of the Great Lakes and their basin has not only been reviewed but largely increased by the exploration and investigations of Dr. H. E. Hurst, Director General of the Physical Department of the Egyptian Government, and in the two volumes of his work " The Lake Plateau Basin of the Nile " is to be found all that is known about this subject. The work has been frequently used in this note especially for compiling the part of the following description of the Nile Valley, which deals with its course from the Lake Plateau to Nimule, where it enters the Sudan.

Lake Victoria is an enormous inland sea, the largest fresh water lake in the Eastern Hemisphere, of an area of about 69,000 square kilometres (including the area of the islands which is about 2,500 square kilos.) and lies about 1,134 metres above M.S.L. at Mombassa. The longest river entering it is the Kagera, about 670 kilos. long from its farthest source to its mouth, and it is usual to count the head-waters of this river as being the source of the Nile, whose length from its source to the Sea is over 6,500 kilometres. The average discharge of the Kagera is probably not greater than 350 cubic metres per second.

The Nile leaves Lake Victoria at the northern end over the Ripon Falls and is called the Victoria Nile on the reach from the Lake Victoria to Lake Albert. It flows first through a fairly narrow valley over rapids and rocks for about seventy-five kilometres

to Namasagali, where the valley widens out and the river becomes a broad smooth stream fringed with swamps till it reaches Lake Kioga, at about 125 kilos. from the Ripon Falls. This is a shallow lake consisting of a number of arms, many of which are overgrown with swamp vegetation. The effect of this Lake on the flow of the river is to introduce a lag on the discharge from Lake Victoria of the order of four months. As to its actual quantitative effect, it may be stated that it is probable that at the end of the dry season Lake Kioga is a sink in which water is lost from the Victoria Nile, while later on water flows back into the river. On the average it is likely that the total gain or loss is not large.

After leaving this lake the river continues as the same kind of stream for some distance till it goes over a number of rapids including the Murchison Falls and then about thirty-five kilos. further on enters Lake Albert, the length from Lake Victoria to here being 380 kilometres. The fall from Lake Victoria to Lake Albert is about 516 metres.

" Hydrographical information from the Lake Plateau basin is scanty. It consists of daily gauge readings extending over periods up to twenty-five years for a few points in the system, rainfall and meteorological observations for similar periods and a very few discharge observations. Without regular discharge measurements extending over long periods it is impossible to make more than a very general study of the regime of the Lakes. Some conclusions can however be drawn from the existing information. These conclusions must be taken as probable deductions subject to confirmation by further evidence, and also as indicating the directions in which work is required".

The foregoing quotation is from Dr. Hurst's book above-named, and bearing in mind his warning as to the reliability of the figures, it may be said that the mean monthly discharge (1913–1923) leaving Lake Victoria over the Ripon Falls is 610 cubic metres per second, while below Lake Kioga at Masindi it is 670 cubic metres per second. (The difference between the two figures is not significant). The maximum discharge of Lake Victoria has probably been over 1,000 cubic metres per second and the mean discharge of the lowest year is probably about 380 cubic metres per second, falling as low as 350 cubic metres per second. The catchment area to this point is about 336,000 square kilometres.

It has been suggested that the discharge of the Nile and hence the water supply of Egypt might be increased by carrying out works (such as lowering the Ripon Falls at the exit of Lake Victoria) for increasing the quantity of water entering Lake Albert, and hence also the quantity leaving that Lake through the Nile. That some such works may have to be carried out in the future is probable, but firstly it will be shown that no increase in the waters leaving Lake Albert can benefit Egypt to any appreciable extent till vast projects have been completed in the swamps of the Southern Sudan and secondly there are no data, hydrologic or geographic, available on which any such projects can be based. The collection of the necessary data should be given a place in the scheme of investigation, but no energies should be diverted there till all arrangements are complete and in full swing for collecting the data regarding Lake Albert and the Nile Basin below Lake Albert, data whose lack forms a serious impediment to the preparation and execution of the projects which must inevitably precede any work on the Victoria Nile.

Lake Albert.

Lake Albert is much smaller than Lake Victoria having an area of only about 5,300 square kilometres. The Victoria Nile enters it near the North end and a strong stream flows across the corner, and at a distance of three or four kilometres from the mouth of the Victoria Nile, the Albert Nile (or Bahr el Gebel) leaves the Lake. Lake Albert is destined to form an important feature of any scheme of Nile Control, as it is the ideal reservoir site near the head of the system. Its area is so large that a change of level of one metre affords more than double the storage capacity of the Aswân Reservoir. Moreover its sides are for the most part very steep, so that an increase in level would not, it is thought, entail any large increase in area and hence evaporation losses. An important river, the Semliki (or Etuli) whose length is about 250 kilos. enters the Lake at the Southern end flowing from Lake Edward. Its discharge was measured in February 1903 by Sir William Garstin and found to be ninety-seven cubic metres per second, and by Mr. Tottenham's mission in April 1923 and found to be ninety cubic metres per second. There are however indications

to show that the discharge may run as high as 600 or 700 cubic metres per second, or even more. It is therefore by no means a negligible contribution to the waters entering Lake Albert, being perhaps about ¼ to ⅓ of the size of the Victoria Nile.

The Delta formed by the Semliki River entering the Lake is a swampy plain, which forms an exception to the otherwise steep sides of Lake Albert. This fact may have a not un-important bearing on the design of the Lake Albert Reservoir, for it seems not impossible that under certain variations of level this plain might increase substantially the area of Lake Albert and hence the evaporation losses.

The discharge of the Albert Nile at its head has not been measured very frequently, but from such data as are available, Dr. Hurst has calculated that its mean annual discharge is of the order of 800 cubic metres per second, though in some years it falls much below this.

The catchment area of the Lake Albert system is about 53,000 square kilometres so that the total catchment area of the Nile up to its exit from Lake Albert is the sum of Lake Victoria system 336,000 square kilometres plus Lake Albert system 53,000 square kilometres or a total of 389,000 square kilometres.

The Albert Nile.

On leaving Lake Albert, the river is known as the Albert Nile on the reach from here to Nimule. At about fifteen kilometres from the Lake (at Pakwatch) is the site which Sir William Garstin and subsequent observers considered to be probably the best for a dam for turning Lake Albert into a Reservoir, as low hills here approach the river. The river soon narrows from its wide mouth to a width of about one kilo. and then gradually decreases and as far as Nimule (216 kilos. from Lake Albert) flows in a smooth winding stream, with an open water width of 100 to 300 metres, bordered on each side by swamp whose width is not known. It is of the same nature as the swamp further North, to be described later, but not nearly so extensive. The river is in many places very shallow, especially at Lake Rubi, some 50 kilos. from the Lake. On the reach Lake Albert to Nimule there are many minor tributaries and two fairly important ones, the River Achwa (not to be confused with the Achwa or Assua, a tributary North of Nimule) and the Unyama.

Practically nothing is known about the hydrology of this reach. The country has been cleared of inhabitants on account of sleeping sickness, and the only discharges ever taken have been those at the outlet from the Lake. From observations at Nimule it seems not improbable that the quantity of water entering the river from tributaries and direct drainage is considerable in the flood months, but whether the losses due to evaporation from the swamps are heavy in the summer is not known.

The Bahr el Gebel, Nimule to Rejaf.

At Nimule (about 615 metres above Alexandria M.S.L.) is the Uganda boundary and the river enters the Anglo-Egyptian Sudan, and is henceforth known as the Bahr el Gebel, till it joins the Bahr el Ghazal, north of the Swamps.

Its nature changes as it here becomes a rapid stream flowing over falls and cataracts for 160 kilos. to Rejaf, about 460 metres above Alexandria M.S.L., the southern limit of navigation on the Nile. There are three principal rapids and many minor ones and as the river is everywhere on this reach well within its banks, the transmission losses between Nimule and Rejaf must be negligible at all seasons. There are three tributaries on this reach each draining a considerable area, namely the Assua and Kit Rivers on the right bank and the Kaia river on the left bank, and also a number of small ones. The dry season flow of these streams is very small—the Assua is the biggest and this falls to ten cubic metres per second or less in summer. In flood, however, the discharge of each may be very hig for short periods, of the order of 200 to 300 cubic metres per second or more. Thus spates may enter the Bahr el Gebel increasing its discharge at Rejaf by at least as much as 600 or 700 cubic metres per second for a few days and perhaps by very much more.

It will be understood from the foregoing that though in summer practically all the water that passes Rejaf comes from Lake Albert, yet during the flood months a great deal

enters the river direct on these 370 kilos. This fact is of considerable importance in connection with future regulation of the River by a dam at Lake Albert, and it is obviously necessary to ascertain exactly how much water comes out of the Lake and could therefore be impounded there and how much comes in below the Lake and therefore cannot be controlled there. This can only be done by taking regular measurements at the Lake outlet and the establishment of a river gauging station (levels and discharges) here is perhaps the most urgent measure that requires to be taken in connection with the studies for the Lake Albert Dam and Sudd Channel. A regular river gauging station was established at Nimule in January 1923. Unfortunately the best site for taking discharges was in an area recently infected with sleeping sickness and its use was forbidden by the Medical authorities till the site had been clear for two years. It was not till February 1925 that permission was given to use the best site, and during 1923 and 1924 the river was gauged at another site, where turbulence of the water affected the current meter measurements. The measurements for 1923–24 are not valueless, for by comparison of the gauges with the gauges and discharges of subsequent years the necessary corrections can be applied to the earlier observations.

This is the furthest South river-gauging station maintained by the Egyptian Government and staffed by its officials, over 6,000 kilometres and nearly six weeks' journey from Cairo.

Rejaf to Mongalla.

At Rejaf the river changes its character and becomes a smooth flowing stream with a fairly strong current. For some kilos. beyond Rejaf the bed is wide, the banks high and the waters very shallow, especially in summer. The river is here for a short length all in one channel even in flood, a condition that does not recur for nearly 1,000 kilometres of its course. It soon becomes broken up by large islands, often very low lying, and swampy berms appear, though high banks still come down to the water's edge frequently, first on one side and then the other. Such high land is always covered with Savannah forest.

Gondokoro lies on the right bank twenty-one kilometres from Rejaf. It was the Uganda—Sudan boundary on that bank, till the cession of the Lado Enclave and the subsequent readjustment of boundaries in 1910. Sir Samuel Baker had a fort here and used this as the base for his expedition when he discovered Lake Albert in the sixties of last century.

At 58 kilometres from Rejaf Mongalla is reached, the capital of Mongalla province.

This is a name of importance in the hydrology of the Nile, for gauges and discharges have been measured here for many years. Two tributaries join the Nile between Rejaf and Mongalla, namely the Khors Koda and Luri both on the left bank, but below Mongalla no further waters are known definitely to join the Bahr el Gebel, till we come to the Bahr el Ghazal beyond the swamps over 750 kilometres to the North. The catchment area from Lake Albert to Mongalla is about 82,000 square kilometres, making the total catchment area of the Bahr el Gebel at Mongalla about 471,000 square kilometres.

Thus the waters we have to deal with in considering schemes for improving Egypt's water supply are the waters that pass Mongalla and may be conveniently referred to as the Mongalla discharge. Everything that comes from the Lake Plateau and from the area below Lake Albert, but above Mongalla, has to pass Mongalla, and nothing more comes into the Nile from this part of the basin. Any project for increasing Egypt's water supply from this main region must increase the Mongalla discharge and it is the Mongalla discharge that must be carried with as little loss as possible through the Swamps to the White Nile and on to Egypt.

Regular discharge observations were begun at Mongalla in March 1922. From 1905 to 1921, twenty-nine discharge observations were taken at or near Mongalla and the river gauge at Mongalla read daily. From these data a gauge-discharge curve for Mongalla has been made for the above years and from this curve are deduced the figures used for all calculations in regard to Mongalla discharges prior to 1922. Naturally, a high order of accuracy is not to be expected from figures so obtained but it is probable that the error does not exceed 20 per cent. The average monthly discharge at Mongalla varies from about 650 cubic metres per second in March to 920 cubic metres per second in August and October, the highest ever observed being 2,830 cubic metres per second in October 1917 and the lowest 298 cubic metres per second on 14th March 1923. The river at Mongalla is all in one channel except at very high levels, when a Khor on the west side begins to flow.

As this Khor is full of reeds it is difficult to measure its discharge and therefore above a certain level, discharge observations are suspended at Mongalla and taken at Rejaf instead, where the river is in one channel at all levels and at high levels the section is not unsuitable for current meter observations. By taking the discharge at Rejaf instead of Mongalla, the contributions of the Khors Koda and Luri, mentioned above, are not included in the Bahr el Gebel discharge, but these two Khors are not very important, and the inaccuracy introduced by neglecting them is probably less than that introduced by neglecting the western Khor at Mongalla. Both these Khors enter the river through large swampy berms in which their discharges cannot be measured, but if they were ever of any importance they would produce peaks on the Mongalla gauge curve that would not be present on the Rejaf gauge curve and the volumes added could be estimated with sufficient accuracy by calculating the discharges represented by such peaks.

MONGALLA TO BOR.

From Mongalla to Bor (128 kilometres) the river is in a transitionary state and its valley becomes more and more swamp like. The high land recedes further from the channel and islands and berms become larger and more swampy, though the high land still comes down to the river's edge with some frequency—the river in fact winds about in a flat valley 5 to 10 kilometres wide. At low water there is only one navigable channel and that is full of shoals, but there are usually one or two other channels with water in them. As the river level rises, side channels, pools and swamps all fill up and not only absorb large quantities of water in filling but once filled constitute a permanent drain on the river owing to evaporation losses. The river from Mongalla to Bor is imperfectly understood from the hydrologic point of view. Gauges have been observed with more or less regularity at Tombe and Malek, between Mongalla and Bor, for a varying number of years, and regularly at Bor since 1905, but very few discharges have been measured, only between 30 and 40 at Bor up to 1925, in which year a discharge measuring station was established at the latter place and regular observations begun. The maximum discharge normally obtainable at Bor is about 800 cubic metres per second, the mean monthly discharge varying from about 240 cubic metres per second in February to 760 cubic metres per second in August. Where the water disappears to between Mongalla and Bor is not known. There may be connections between the swampy areas on the west bank and the Sudd swamps below Bor, for this country is practically unexplored on that side, but there do not seem to be any on the east side. An alleged river, called the Gell, enters the Bahr el Gebel below Bor on the west bank, but whether this is a true river bringing in new water or whether it is fed by spills from the main river is not known. Its mouth is thickly covered with swamp growth and its discharge cannot be measured, but is certainly only a trifling proportion of the losses between Mongalla and Bor. It is important to bear in mind that without an extensive remodelling of the Bahr el Gebel above Bor it will not be possible greatly to augment the discharge reaching Bor, and that such work should therefore have an early place in any series of projects intended to deal with the Upper Nile problem. The regular discharge observations that were begun at Bor in 1925 have hardly lasted long enough yet(*) to enable reliable deductions to be drawn from them in a comparison with the Mongalla discharges but it is not improbable that at the levels which are necessary for a discharge of 800 cubic metres per second at Bor, the loss is over 20 per cent on this reach of 128 kilometres, before the real Swamps begin.

THE SUDD REGION.

Below Bor the bad swamps begin almost at once on the east bank, while the west bank does not get much worse for about another 100 kilometres, but after passing Kenisa, 126 kilometres from Bor, the river flows through unmitigated swamps on both banks for the remainder of its course, 493 kilometres, till it joins the Bahr el Ghazal at Lake No and forms the White Nile. Only at one place in this reach, Ghaba Shambe, 86 kilometres from Kenisa on the west bank, does a strip of high land covered with trees run down through the swamps to a lagoon on the main channel and a track goes from here inland to Wau, the capital of the Bahr el Ghazal province.

Soon after Bor, on the east bank, spills into and out of the swamps from the main channel begin to occur with frequency and some 30 kilometres away to the east is a big

* They were stopped in Feb. 1923 owing to lack of staff.

stream, first discovered by Mr. Grogan and named by him "Gertrude Nile," but now known as the Atem or Awai. This stream flows more or less parallel to the main Bahr el Gebel sometimes as open water forming a fine river and sometimes overgrown with papyrus and other swamp growths, until finally it is lost in impenetrable swamps in the neighbourhood of Shambe, only to start again some 50 kilometres further on as the Zeraf.

The channels leading to and from the Atem and Awai and main Bahr el Gebel have been divided into two groups by the Irrigation Service. Channels in which the water flows from the Bahr el Gebel into the swamps are considered as the heads of streams and those in which the water flows from the swamps into the Bahr el Gebel are considered as escapes or tails. Coming from Bor on the east bank first there is a series of heads named by the Irrigation Service Atem head 1, Atem head 2 etc. and then there comes a series of escapes or tails known as the Atem tail 1, Atem tail 2 etc. After the group of Atem tails there is about one hundred kilometres where no channels of importance enter or leave the swamps till new groups begin which for distinction are called the Awai Heads and Awai Tails, the last of these occurring some 40 kilometres below Ghaba Shambe. All these channels have been identified by the Irrigation Service and for ease of location and reference enamelled name plates have been erected on steel telegraph poles at each of the Awai and Atem Heads and Tails.

Vegetation in the Swamps.

The Bahr el Gebel swamps are densely overgrown with papyrus 15 to 18 feet high, intertwined with creeper, through which it is impossible for a man to force his way except by cutting down the growth. In normal years the tops of the roots are in water varying with the season from a depth of a few centimetres to a metre or so, but the years 1922–1926 showed a new aspect of this region, the swamps being practically dry in spring and summer and the river level being about a metre below the mean plane of the top of the papyrus roots. The most noticeable plant in the swamps is the Papyrus, but there are many others, twenty-two different kinds having been recognized in all. The chief after the papyrus are Um Soof, Elephant grass and Ambatch which are easily recognisable. Where Um Soof is seen, there is water deeper than that in which the papyrus flourishes, while elephant grass and ambatch indicate less water than the papyrus. Very little is known of the habits of these swamp growths and the reason for their exceeding luxuriance in this area, but it seems essential to acquire such knowledge if works are to be carried out here, for otherwise through ignorance a canal may be cut which will provide ideal conditions for their increase. A very noticeable phenomenon was to be observed from about 1923–24, *i.e.* after the very dry year 1922, and that was the sudden appearance of regular small forests of ambatch trees with great frequency throughout the swamp area. Ambatch was usually found in isolated specimens or, at the most, in small clumps, so the appearance of what looked at a distance like dense copses of fine firs, 30 to 40 feet high and often many feddans in extent, could not fail to be noticed. They appear to have grown in the spaces occupied before the years of low water by lagoons of open water. These dried off in 1922, leaving ground entirely free of plant growth, and apparently gave a chance to the ambatch seed to sprout and grow high enough for the tops to be above water when the flood came. They were able to continue living, therefore, during the flood and went on growing till they became forests, as described, in a very short time. Without study by a skilled botanist it is impossible to say that any canalization carried out may not produce conditions favourable for the proliferation of one of the many sudd plants in a similar manner and so wreck any project.

Main and Side Channels in the Swamps.

The main channel of the Bahr el Gebel is a fine navigable stream constantly varying in width according to the number of side channels, from about seventy metres to about 150 metres, while spills into and out of it are sometimes clear water, sometimes overgrown with papyrus and other swamp plants. The frequent lagoons of open water form a distinct feature of the river. They vary in size from small ponds up to an area of about four or five square kilometres with a few larger ones, which are connected by open water channels to the main stream. The recent series of years of low levels has reduced the number of lagoons, for swamp plants have grown in them when the water has been sufficiently shallow for a long enough period. There are said to be a few tributaries running into the swamps, the chief being the R. Yei or Lau which rises south of Mongalla. It has never been traced

to its end and it is not certain whether it flows into the swamps of the Bahr el Gebel or Bahr el Ghazal. It is not an important stream normally. South of Shambe the main swamps are on the east of the river, but north of this place they get narrower on the east and wider on the west, until they become more important on the west.

The Bahr el Zeraf.

About 70 kilometres north of Shambe the Bahr el Zeraf has defined itself as a distinct stream on the east and about 30 kilometres farther on it approaches within about 4 kilometres of the main stream and is joined to it by two channels dredged by the Irrigation Service in 1910 and 1913 to connect the two rivers of which the southern one, having been first in time, is known as the Zeraf Cut 1, and the northern one as Zeraf Cut 2. Upstream of its junction with the tail of the Zeraf Cut 1 the Zeraf is known as the Upper Zeraf, and down stream of this point as the Bahr el Zeraf. Some few kilometres downstream of the Cuts the Bahr el Zeraf trends to the east again, away from the Bahr el Gebel. High land covered with Dom palms appears between the two streams and the swamps round the Bahr el Zeraf gradually die out until it flows at 125 kilometres downstream of the Cuts in a fairly clean but very winding channel and looks like a big irrigation drain with rather bad reed growth on the sides.

The Bahr el Gebel below the Cuts continues unchanged to its end at Lake No the same dreary wilderness of papyrus, with only two small patches of high land that are dry at all seasons of the year, one called Hellet Nuer on the west bank about 80 kilometres from the Cuts, and the other Buffalo Cape, 150 kilometres further downstream on the east bank. There is also a patch on the east bank, 15 kilometres above the Cuts, known as Ghabet Inderab. Gauges have been in existence at these places for many years and have been read as opportunity arose during the tour of an Irrigation official. Since 1925 they have been read regularly at fortnightly intervals, through the courtesy of the Sudan Government Steamers Department who stop their fortnightly post-boat long enough at each gauge for a travelling gauge reader of the Irrigation Service to get off and take an observation.

The geography of the west side of the Swamps below Ghaba Shambe has been elucidated of late years. There is a channel, known as Peake's channel, that takes off the Bahr el Gebel on the west some 40 kilometres above the Cuts and joins it again 6 kilometres below Cut 2. In 1923 the head of this channel was clearly defined and a discharge measured, but by the following year the head was completely choked with papyrus, though the tail was still flowing freely. About 9 or 10 kilometres below the tail of Peake's Channel, Fell's Channel opens on the left and flows for about 50 kilometres in a separate stream before it rejoins the main river a few kilometres above Hellet Nuer. On its course it is fed by several small spills. A third channel of some size known as Gage's Channel starts at Hellet Nuer on the west bank. It is completely overgrown with papyrus and very difficult to trace in the swamps, but in 1926 the late Captain Ferguson (who was murdered by the Nuers in December 1927) traced it all the way to its mouth and found that it was the same as a channel known as Khor Doleib, which joins the Bahr el Ghazal on the latter's right bank, about 28 kilometres from the junction of the Bahr el Ghazal with the Bahr el Gebel. Gage's Channel therefore forms a cross connection between the Gebel and Ghazal systems. It is of no importance at present, the discharge being trifling, but is of great interest. There are no channels of any size opening on the right bank of the Bahr el Gebel below the Cuts, though there used to be one, called Maya Tawila, about 15 years ago, but this is now completely overgrown and impossible to locate.

It is very important to know exactly where these various channels leave and enter the main system, otherwise discharge measurements give a false idea of its regime. As such junctions are often cloaked by plant growth and easily missed, observations of discharges are at times extremely discordant and difficult to explain in the absence of such knowledge.

Islands in the Swamps.

The swamps below Shambe are bounded on the west by a low wide ridge at a distance of about 10 kilometres from the main stream. The Nuers graze their cattle here and have

a great many scattered collections of huts. The so-called ridge, which only has an altitude of a metre or two above the swamps, seems to form a sort of water shed between the Bahr el Gebel swamps and the Bahr el Ghazal swamps that are formed by rivers coming down from the Nile-Congo water shed. There are numerous gaps and Khors overgrown with swamp vegetation in the above Gebel—Ghazal ridge and it may well be that waters from the Ghazal basin enter the Gebel swamps and *vice-versa*, but there is no evidence on the point one way or the other.

Till recently it was thought that the Bahr el Gebel swamps contained practically no land that was ever solid but in 1925 and 1926 very large islands were discovered. These islands are uncovered in the summer and used for grazing cattle, as the ground is not covered with a tangle of decaying papyrus roots and so on, like the true swamp, but with grass.

The first was discovered by Mr. H.G. Bambridge of the Irrigation Service in 1925 and is in the eastern swamps a little south of Shambe, the other was discovered by the late Captain Ferguson, and is a long narrow strip in the western swamps stretching from about Shambe to about the Bahr el Ghazal and lying between the main river and the Gebel—Ghazal Ridge above described. Bambridge's island is about 60 kilometres long by 15 kilometres broad and Ferguson's island about 400 kilometres by 2 kilometres. The area of the two is about 1,700 square kilometres, a very high proportion of the total swamp area, which (including these islands) is believed to be about 5,000 square kilometres on the average.

Bambridge's island is really a continuation of the island of Akowit mentioned by Sir W. Garstin and believed by him to be only a few square kilometres in area. It is important to the Nuers for its grazing, as is also the main land of similar quality to the east of the swamps in this neighbourhood. Whether these grazing lands are flooded by the rise of the Bahr el Gebel or by rain water flowing down in Khors and over the land from the Abyssinian mountains or by both, is not known. It is of some importance to gather information on this point, for the construction of a large channel here may cut off the land from its water supply, either by intercepting the rain water flowing westwards to the island or preventing the flood water flowing eastwards to the grazing on the main land.

In general terms then the Swamp region consists for the first 250 kilometres from the south of the main stream, the Bahr el Gebel, with a subsidiary stream known successively as the Atem, the Awai and the Zeraf, at a distance on the east varying from about 30 to about 4 kilometres while after the Bahr el Zeraf has finally turned away to the east, there in only one main stream for the remaining 250 kilometres length. In addition throughout the whole length there are numerous false channels some of open water, some overgrown with swamp vegetation, leaving and rejoining the main stream.

THE SUDD BLOCKS.

The Bahr el Gebel is now navigable all through, though it was completely closed for many years during the Mahdi's rebellion and for some time after by the so-called " Sudd Blocks."

These are simply immense masses of floating vegetation, densely intertwined and compacted by the force of the current. They stick at some narrow twisting part of the river, close the main channel and force the water to spread itself through the swamps in a number of shallow false channels. The current in the main channel dies away and silt accumulates beneath the floating sudd, part of which (especially the papyrus) takes root in this soft mud. The floating vegetation becomes so solid that men can walk on it and the only way to clear it and restore the river to its original channel is for men to hack large sections of it free from the rest with axes and bill-hooks, pass a hawser round the detached portion and tow it away to the main stream, where the current disintegrates it and carries it away. Great care must be exercised that the broken up Sudd does not collect again downstream and form a new block.

In the year 1899, immediately after the Reconquest, the Nile was very low and it seemed that water levels could be raised by clearing the river and allowing the water to flow in its best channel instead of spreading out in lagoons and the hope seems to have been entertained that the lagoons and swamps would dry up to a very large extent if the Sudd was

cut. It was also of great importance to establish good river communication between Khartoum and the South at the earliest date. After Sir William Garstin's visit to the Sudd Region in 1899 the Egyptian Government therefore gave a grant of L.E. 10,000 for clearing the Sudd and a further L.E. 4,000 in 1901. There were 19 Sudd blocks altogether between Buffalo Cape and Ghaba Shambe and all but No. 15 and 16 near Hellet Nuer were cleared in the four seasons 1899–1900–1901–1902. The labour employed consisted of prisoners of war and ex-dervishes, and also a party of a hundred women, the number of persons working on the Sudd and on wood cutting for fuel for the steamers reaching as many as 800. The whole work was done under the direction and command of Commanders Peake, Fell and Drury, of the British Navy.

In 1901 Sir William Garstin decided that the Sudd cutting did not materially improve the water supply of Egypt and no further grants were made to complete the clearance of the main channel of the above mentioned blocks 15 and 16 (about 40 kilometres long) which were very formidable. After Sir William Garstin's next visit to the Sudan in 1903, he however came to the conclusion that though no direct and immediate increase in Egypt's water supply was likely to result, yet in view of the necessity for beginning a study of the Upper Nile for the purpose of preparing projects for its control, it was necessary to restore the river to its normal condition and ensure through navigation on the Bahr el Gebel.

The work was therefore continued in the seasons 1903–4–5 under the direction of Colonel Matthews and then of Commanders Drury and Bond, the working party consisting of convicts and "Undesirables" from Omdurman all of whom worked extraordinarily well, the cost being a further L.E. 12,000 granted by the Egyptian Government, bringing the total up to L.E. 26,000. The blocks were cut through by January 1905, but another few months were taken in clearing the channel to its full width and removing the remains of the floating Sudd to prevent any immediate recurrence of a block. The danger is by no means over for as late as the autumn of 1926 the river was blocked above Shambe on a length of about 8 kilometres for two or three weeks till a Sudd cutting party from Khartoum arrived and cleared the block.(*) There had been several years of abnormally low water in summer and flood in the Upper Nile prior to 1926, which was a high flood and seems to have loosened large areas of recent and loosely-rooted vegetation in the lagoons, and carried it downstream in gradually increasing masses till it choked one of the narrow winding channels above Shambe, where a large proportion of the Bahr el Gebel flow is taken in the side channel, the Awai, thus reducing the width and discharge of the main stream.

The rivers Atem, Awai and Zeraf are not navigable as a continuous line. Sir Samuel Baker forced his way up the Zeraf in 1871 and got out into the Bahr el Gebel about 60 kilometres above the present Zeraf Cuts. This channel was opened up by the Irrigation Service about fifteen years ago but is now again closed. The rivers Atem and Awai are both navigable on some reaches and can usually be reached by shallow draft steamers from the Bahr el Gebel, while the Bahr el Zeraf is navigable for large steamers from the Cuts to the mouth.

The Bahr el Ghazal.

The Sudd Region ends at Lake No—a shallow sheet of water through which the Bahr el Ghazal flows to join the Bahr el Gebel. From the junction of the two streams the river is known as the White Nile. The Bahr el Ghazal is a stream of small hydrologic importance, its discharge occasionally falling to nil, while the highest observed discharge has been 89 cubic metres per second in October 1926. For many years the Irrigation Service in all calculations assumed the discharge of this river was a steady 20 cubic metres per second, but though the average discharge does not differ much from this figure, yet it is not safe to use it in making calculations for particular months for it is of the same order as the monthly variation in the discharge of the Bahr el Gebel, and such an assumption may therefore completely mask variations in the latter's flow. In 1923 the taking of discharges regularly was begun here and since then its flow has been measured every ten days. The cross connection formed by Gage's Channel between the Bahr el Gebel and Bahr el Ghazal systems has already been mentioned. There may also at times be a slight flow direct through the swamps from one to the other but the total quantity is so slight that no conclusive evidence on the point has been obtained from measurements. The Bahr el Ghazal is a river of which

(*) There was another bad block in about the same place in 1928.

very little is known. It has several tributaries the chief being the River Jur and the Bahr el Arab (about both of which also our hydrologic knowledge is nil) and though its catchment area is about 550,000 square kilometres with a mean annual rainfall of about one metre, yet its discharge at Lake No is insignificant, as has been shown, owing to the flat nature of the ground reducing the run-off and the large swamps causing heavy evaporation and transpiration losses from plants. It is however important as the main line of communication with the important Bahr el Ghazal province, navigation being possible from the White Nile through the Bahr el Ghazal and Jur River to Wau, the capital.

The White Nile.

The White Nile flows at first nearly due east in a wide shallow valley. The trough of the main river is clearly defined and is a good channel, but there are wide swampy berms on either side on which not inconsiderable loss from evaporation occurs when the river rises. At 78 kilometres from Lake No, the Bahr el Zeraf joins the White Nile, the valley has become narrower here and the swampy berms less, there being dry land practically continuously on the right bank. Below the Zeraf junction the White Nile now carries all the water that has managed to get through the swamps from the Great Lakes and the southern catchment area, its mean discharge being 14,450 million cubic metres per annum. Compare this with the mean discharge for Mongalla 27,535 million cubic metres and it will be seen that there is a mean annual loss of water of over 13,000 million cubic metres between Mongalla and Malakal.

The prevention of this loss and the transmission of the water conserved in accordance with the seasonal requirements of cultivation in Egypt form the problem of the Sudd Region of the Upper Nile.

The White Nile has several parallel channels within its valley for about the first 120 kilometres of its course on either side of the main channel. One of these, Khor Lolle on the left bank, may perhaps have an independent source and bring waters from the Bahr el Arab basin, but this is not known for certain. Attempts were made in the years 1911–1913 to improve the carrying capacity of this reach of the White Nile by dredging cuts from the main channel to the side channels through the intervening swampy berms. There is no evidence as to whether these cuts ever had any effect and they are now completely choked by sudd and the Khor Lolle is itself closed by a bank carrying the main road to the Nuba Mountains province. Where the head of the Khor Lolle is, is not known but it joins the White Nile at 118 kilometres from Lake No while 2 kilometres further on another wide Khor, the Bahr el Harami, takes off the White Nile and rejoins the White Nile about 18 kilometres further on again. The position of these two Khors, Lolle and Harami, is of interest and may be of importance in future schemes of development, as they could be connected by very little work to form one channel, parallel to the White Nile on the high ground on the edge of its valley, and thus form an alternative route, either for water or navigation or both, from the White Nile to the Bahr el Gebel and Bahr el Ghazal.

River Sobat and its Branches.

Forty-five kilometres after passing the Zeraf mouth, the junction of the River Sobat with the White Nile is reached on the latter's right bank. The Sobat is the most important tributary of the White Nile or Bahr el Gebel, its mean discharge being about 450 cubic metres per second with a mean maximum of about 800 cubic metres per second in October and November and a mean minimum of about 100 cubic metres per second in April. It is the chief source of Egypt's winter water supply and gives an increased supply at Aswân in the early summer before the Bahr el Gebel at Mongalla does for though the latter rises about one month earlier, yet it takes about three months to reach the Sobat mouth.

The river Sobat is formed by the confluence of the Rivers Baro and Pibor 335 kilometres from its mouth. The river Baro rises in Abyssinia and has numerous tributaries of which little is known. Its discharge has only been measured very seldom* where it issues from the hills at Gambeila (the Sudan enclave within the Abyssinian border) but such discharges compared with its discharges at its junction with the Pibor, 220 kilometres to the north, show a very heavy loss in the rising flood in September. The main part of this loss is incurred in flooding the dreary grass plains chiefly on its left bank between it and the Pibor,

* Regular discharge observations were begun here in Autumn 1928.

but definite spills also occur on the right bank through which the water flows to feed swamp between the Sobat and the White Nile towards Melut on the latter river and some of the spilt water may return to the White Nile through the Khor Adar which joins it near Melut.

Proposals have been made for closing these spills and thus increasing the water flowing in the river but while the banks, especially the left, are under water for great lengths in flood, any increase in the discharge and levels would only increase the swamping.

The main spill is the Khor Machar, whose discharge reaches as much as 80 cubic metres per second in flood, but has never been measured in spring and summer. It must be very much less then as the water level probably falls about 3 metres judging from the mean annual variation of Gambeila gauge.

The conditions subsisting in the River Baro from Gambeila to the Baro-Pibor junction seem to be similar to those on the Bahr el Gebel between Mongalla and Bor, *i.e.* any increase in discharge at the upstream site (Gambeila) above a certain figure which may be about 1,100 cubic metres per second is not reflected by a corresponding increase in the downstream site (Baro junction) but is merely wasted in the intervening swamps. As the Baro levels fall in November a certain proportion of the water spilt on the grass plains seems to return to the river and so maintain the discharge of the Sobat, for whereas maximum levels are reached at Gambeila in September and the river then begins to fall, the Sobat has its maximum discharge at the mouth in November about six weeks later.

The River Pibor rises in the grassy swamps between Abyssinia and the southern reaches of the Bahr el Gebel. It has numerous tributaries, the most important being the Rivers Akobo, Agwei and Gila, but is a much smaller stream than the River Baro. Its actual section is about 70 to 80 metres wide, then there is a low berm over which water flows in flood, and then higher land that is swamp. The total discharge in flood is of the order of 300 cubic metres per second when the Baro is about double that amount. It has never been measured in the summer months, nor have any of its tributaries, but as the total Sobat discharge in the summer falls to about 100 to 150 cubic metres per second of which the greater part comes from the Baro, the individual contribution of the Pibor's tributaries must be very small. It is however stated by Sudan Government administrative Officials who have visited the upper regions of the tributaries in the summer that some of them flow strongly in clearly defined beds where they leave the Abyssinian mountains, and that the swamps in which they get lost have been formed by obstructions, such as trees, falling in the river bed and causing sudd blocks and thus swamps.

The investigation of this river system is very difficult for the region is only accessible by steamer in flood time, June to October, and to reach it at other periods involves marching many hundred kilometres. Its further investigation is however of great importance, for undoubtedly large quantities of water are lost there, which might perhaps be conserved by works of not great difficulty or expense. The improvement of channels by removal of obstructions and closing of spills might cause an immediate increase in summer and the construction of Nile banks on the River Baro for a length of about 200 kilometres might increase the Autumn supply of the Nile and thus relieve all difficulty in filling reservoirs at Gebel Aulia or Aswân or both sites. An essential preliminary however is hydrologic investigation—the establishment of discharge observation stations at Gambeila and the Baro mouth—for it may be found that most of the water spilt out of the River Baro in September and October flows back in November and December. The River Sobat itself from its formation by the junction of the Rivers Baro and Pibor flows in a good channel to its junction with the White Nile. There is very little swamp on its berms which are not wide, while the neighbouring country is a flat grass plain, fairly populated and not subject to flooding in ordinary years. There is a mission station and military post at Nasser, 42 kilometres below the Baro-Pibor junction, with a gauge that is regularly recorded and connected by precise levelling with Khartoum and the whole system of gauges on the Nile. There are also gauges at Akobo and Pibor Post on the River Pibor, but they have not been levelled.

At Hillet Doleib about 8 kilometres from the junction of the River Sobat and White Nile there is a mission station and gauge which has been regularly observed for over twenty years.

Discharges have been observed here with varying regularity for a long period and since 1922 at regular intervals of five days. Our chief knowledge of the Sobat regime depends on these discharge observations.

No discharges have been recorded regularly at Nasser, but judging from the movement of the Nasser gauge the maximum occurs here two or three weeks before the maximum at the mouth, instead of two or three days before. There are numerous Khors of considerable size, the chief being Khor Filus, which join the river on its west bank below Nasser and it seems as though these drain considerable swamp areas in the interior and thus prevent the Hillet Doleib discharge falling consistently with the Nasser discharge.

WHITE NILE (*continued*).

To return to the White Nile : there is the usual ponding up effect in flood at the junction of the River Sobat and the White Nile for the former has a steep slope and the latter a very flat one, being of the order of one centimetre per kilometre and even less in flood. This ponding up may reach as far back as Lake No at times and thus cause evaporation losses in the White Nile by forcing it to flow at high levels and spread over the swampy berms previously described.

As the levels in the White Nile are largely determined by the River Sobat, during the summer when it is low there is a good slope from Lake No and the White Nile can carry 750 cubic metres per second, whereas in flood when the River Sobat is high, the same White Nile Channel cannot carry more than 400 cubic metres per second without heavy loss. Above 750 cubic metres per second even with summer levels and slopes, the spilling becomes very large and heavy remodelling and embanking would be required to prevent undue loss.

At the mouth of the Sobat are the remains of the old fort built by Sir Samuel Baker who was sent by the Khedive Tawfik to put down the slave trade about sixty years ago.

An island 18 kilometres long is formed here by the White Nile and the Bahr el Harami previously described. The fort was put at the junction of the River Sobat and White Nile to stop the trade on both rivers, but the slavers used to get past the fort at night by keeping up the Bahr el Harami (hence its name) instead of the main channel of the White Nile.

Nine kilometres below the Sobat mouth is Tawfiqia, which was Sir Samuel Baker's headquarters. There is a gauge here which has been erected and observed by the Irrigation Service for over twenty years. Baker also measured the rise and fall of the river while he was there and one year he records that the variation was fourteen feet *i.e.* about 4.30 metres. Even if the observation is not strictly accurate, it vastly exceeds any variation that has been recorded in one year since 1904 and is a warning not to think that the Upper Nile has shown all its possible vagaries in the twenty odd years it has been studied.

After the Sobat mouth the main channel of the White Nile is larger, containing many islands usually covered in flood, while the river trough absorbs a lot of water on the rising flood. At 23 kilometres below the Sobat mouth (14 kilometres from Tawfiqia) on the right bank is Malakal, the headquarters of the Upper White Nile Division of the Egyptian Irrigation Service. Malakal was founded in 1905–1906 and ten to twelve years later the Sudan Government moved to here the capital of the Upper Nile province from Kodok and the Military headquarters from Tawfiqia. Malakal was chosen because it stands on ground that is two or three metres higher than the general levels of the surrounding land, a matter of great importance in so flat a country. Discharges of the White Nile have been regularly observed here for many years, as this river is here complete. It has been formed by the Bahr el Gebel, Bahr el Ghazal, Bahr el Zeraf and the River Sobat and receives no tributaries on its further course to Khartoum with the exception of the Khor Adar near Melut (142 kilometres north of Malakal). The discharge of the Khor Adar is very small and appears never to have been measured. Its water may be drainage of rain water or partly spilt from the River Baro.

After leaving Malakal the river gradually begins to run North, instead of East, and the swampy islands and berms, together with the forest bordering the high water line gradually begin to die out while the river flows in a wide stream that is comparatively shallow for most of its section. At about Kosti Bridge where the Kordofan Railway crosses the river, 494 kilos. North of Malakal (324 kilos. from Khartoum) the river enters the desert reach. Its water-way is very wide and, except the navigable channel, very shallow. The berms are very flat sloping sandy beaches, cultivated in dhurra and lubia and the like as the flood falls, and sandy dubbas are frequent, while forest and trees become very scarce.

This reach of the river is very flat, the whole fall (in summer) from the Sobat mouth to Khartoum, 840 kilometres, being only about twelve metres while from Kosti Bridge to Khartoum it is less than four metres in summer. The average discharge of the White Nile at its junction with the Blue Nile varies from about 550 cubic metres per second in April to about 1,400 cubic metres per second in October.

The Blue Nile.

At Khartoum, the White Nile joins the Blue Nile and the combined streams are from here on known as the Main Nile. The Blue Nile rises in Lake Tana in Abyssinia at an altitude of 1,850 metres and flows out of the Lake over a rocky ledge and cataracts in a valley that gets deeper and deeper below the general level of the land, until it enters the flat plains of the Sudan a little south of Roseires. A great part of its course in Abyssinia has never been explored and the country is not properly mapped. Two big streams, the Didessa and Debus, enter the river in Abyssinia and many smaller ones, all of which are of a torrential nature and nothing is known of them. Lower down, in the Sudan, two other rivers, the Rahad and the Dinder, join the Blue Nile. Regular measurements have been made of their discharges in flood, since 1922, the Rahad reaching about 170 cubic metres per second in September and the Dinder 420 cubic metres per second. In the summer they dry up into strings of pools and have no discharge, while their total annual discharge is about one milliard cubic metres and 2.6 milliard cubic metres respectively. The discharge of the Blue Nile varies from an average of about 120 cubic metres per second during April to about 6,500 cubic metres per second in August the minimum " ten-day " mean observed being 43 cubic metres per second and the maximum 9,234 cubic metres per second. Only a small proportion of this great flood comes from Lake Tana, as was proved by an expedition that was maintained there from 1920–1924 by the Egyptian Government for the purpose of studying the hydrology and making surveys of the head-waters of this most important river, which is the true Father of Egypt as it is the Blue Nile that furnishes the silt of which Egypt is composed. This silt is also an important factor in determining methods of controlling the Nile, for while a river is full of silt it cannot be dammed to form a reservoir, as the latter would soon be choked by deposits of mud. Hence any schemes for damming the Nile must be so designed as to act only when the water is fairly free of depositable silt. The Main Nile in flood consists chiefly of Blue Nile water and is nearly as silty, hence the same restrictions as regards damming it are valid as for the Blue Nile. The White Nile is however comparatively free of silt, having been filtered by the swamps of the Sudd Region, hence a reservoir on this river can be filled at any time of the year without danger of choking it with silt.

The Blue Nile is a river with a steep slope and consequently when it begins to rise quickly at Khartoum in July it ponds up the water flowing at a flat slope in the White Nile, thus decreasing the discharge of the latter, part of which is used in filling the pond that extends for about a distance of 200 kilometres up the White Nile at that season and whose level rises and falls with the level of the Blue Nile at the junction. Sometimes when the Blue Nile rises very rapidly water actually flows back up the White Nile for a short distance.

Gebel Aulia, where it is proposed to build a dam, is situated on the White Nile 47 kilometres from its junction with the Blue Nile. There is a big hill here on the water's edge on the east bank of the river and a rocky bar at a small depth across the river. This therefore forms the best dam site on the White Nile, and the reservoir that can be formed by it is of very large capacity, though owing to the water surface being very large compared with the depth the evaporation losses are necessarily considerable.

There is one other possible reservoir site on the White Nile near Gebelein, 400 kilometres south of Khartoum. There are numerous rock outcrops near here somewhat north of Gebelein itself and probably good foundations for a dam, though the few borings that have been made are not quite conclusive on this point. Preliminary surveys and calculations show that a reservoir of a capacity of about one milliard cubic metres might be formed here.

The River Atbara.

The Main Nile is regularly measured at Tamaniat, about 40 kilometres below Khartoum and has only one tributary after this, the River Atbara, which flows in on the east bank 325 kilometres north of Khartoum, bringing water from the Abyssinian mountains. It only flows for a few months in the year, from June to October, its flood being caused by the

same rains as cause the Blue Nile flood. The flood discharge, it is believed, may reach as much as 6,000 cubic metres per second but regular measurements were only begun in 1922 since when there has been no very high flood. In the summer the river is only a string of pools and has no discharge, like the Rivers Rahad and Dinder. The peak of the Atbara flood at the mouth occurs normally a little before the peak of the Blue Nile flood and it is thought that floods dangerous to Egypt from their height are brought about by the flood peaks of the two rivers happening to coincide.

The Nile is now complete and flows on without further additions to Egypt. Its discharge varies on the average from about 600 cubic metres per second in May to about 8,500 cubic metres per second in September, while the lowest measured discharge has been below 300 cubic metres per second and the highest estimated over 13,000 cubic metres per second.

Below are given Tables I, II and III showing distances of places along the Nile from the source to the Sea and discharges at the important points. The following maps and diagrams are also attached:

Map of Nile Basin.

Map of Bahr el Gebel Basin.

Typical cross sections of the main rivers of the Nile Basin.

Curves showing variation in discharge at the salient points on the Nile's course.

TABLE I.—DISTANCES ALONG THE NILE FROM THE SEA TO THE SOURCES.

(Kilometres).

Place.	Intermediate.	From Sea.	From Aswan.	From Khartum.	From Lake No.
Damietta mouth	0	0	—	—	—
Delta Barrage	242	242	—	—	—
Cairo	23	265	—	—	—
Aswan	942	**1,207**	0	—	—
Halfa	345	1,552	345	—	—
River Atbara mouth	1,205	2,757	1,550	—	—
Khartoum	325	**3,082**	**1,875**	0	—
Gebel Aulia	45	3,127	1,915	45	—
Kosti Bridge	279	3,406	2,194	324	—
Malakal	494	3,900	2,688	**818**	—
River Sobat mouth	23	3,923	2,711	841	—
Bahr el Zeraf mouth	45	3,968	2,756	886	—
Lake No junction ... ... Bahr el Ghazal and Bahr el Gebel	78	4,046	2,834	964	0
Head of Zeraf Cut I	295	4,341	3,129	1,259	**295**
Ghaba Shambe	112	4,458	3,241	1,371	407
Kenisa...	86	4,539	3,327	1,457	493
Bor	126	4,635	3,453	1,583	619
Mongalla	128	4,763	3,581	**1,711**	**741**
Rejaf	58	4,821	3,639	1,769	805
Nimule	216	4,981	3,799	**1,929**	965
Lake Albert, head of Albert Nile	160	**5,197**	**4,015**	**2,145**	**1,181**
Lake Albert, mouth of Victoria Nile	3	5,200	4,018	2,148	1,184
Murchison Falls	35	5,235	4,053	2,183	1,219
Lake Kioga	220	5,455	4,273	2,403	1,439
Ripon Falls, Lake Victoria ..	125	**5,680**	4,398	2,528	1,564
Mouth of R. Kagera, L. Victoria	220	5,900	4,610	2,748	1,784
Source of River Kagera ...	670	6,570	5,280	3,418	2,454

TABLE II.—SHOWING VARIATION IN ANNUAL DISCHARGE OF THE RIVER AT SALIENT POINTS IN ITS COURSE.

NORMAL 1912–1926.

Totals in millions m3 per annum and average m3 per second for year.

No.	Site.	Lowest.			Highest.			Mean.		
		m^3 per second. (average for year.)	Millions per annum.	Date.	m^3 per second (average for year.)	Millions per annum.	Date.	m^3 per second.	Millions per annum.	Date.
1	Victoria Nile at Ripon Falls	390	12,500	1922	1,000	30,600	—	640 610	— —	1896–1923 1913–1923
2	Mouth of Victoria Nile at Lake Albert (*i.e.* below Lake Kioga)	390	12,500	1922	—	—	—	670	—	1913–1923
3	Head of Albert Nile at Lake Albert	410	13,090	1922	—	—	—	800	25,260	1913–1923
4	Bahr el Gebel at Nimule	489	15,420	1923	1,130	35,621	1918	661	20,870	1915–1926
4	,, ,, at Mongalla	684	15,263	1922	1,770	55,811	1917	873	27,536	1912–1926
6	,, ,, at Bor	471	14,868	1922	871	27,471	1917	654	20,635	1912–1926
7	,, ,, at Lake No	293	9,243	1925	303	9,581	1924	297	9,359	1924–1926
8	Bahr el Ghazal at Lake No	17	531	1925	28	874	1926	21	652	1924–1926
9	Bahr el Zeraf at White Nile...	90	2,839	1922	289	9,103	1918	142	4,469	1912–1926
10	White Nile upstream Sobat mouth	349	10,995	1922	675	21,295	1918	458	14,453	1912–1926
11	River Sobat at Mouth	305	9,619	1913	731	23,062	1918	445	14,041	1912–1926
12	White Nile at Malakal	716	22,583	1922	1,407	44,357	1918	896	28,287	1912–1926
13	,, ,, at Mogren	692	21,831	1922	1,354	42,702	1918	842	26,581	1914–1926
14	Blue Nile at Khartoum	815	25,689	1913	2,448	77,201	1917	1,627	51,334	1912–1926
15	Main Nile at Tamaniat	1,464	25,174	1913	3,543	111,741	1917	2,448	77,245	1912–1926
16	,, ,, below Atbara	1,623	51,178	1913	3,827	121,031	1916	2,738	86,369	1912–1926

Remarks on Table II.

Nos.

1, 2 and 3.—Taken from Dr. Hurst's "Lake Plateau Basin of the Nile" (Part I pages 51, 53, 54, 55 and 58).

4.—Years 1915, 1918, 1919, 1920 computed from general discharge curve.
1923-1926 computed from measured discharges.
1916-1917 and 1922 are not included, as there were no gauge readings.

5.—Years 1912 to February 1922 computed from general discharge curve.
March 1922-1926 computed from measured discharges.

6.—August 1915 to April 1916 not recorded.
1912 to January 1925 computed from general discharge curve.
February 1925-1926 computed from measured discharges.

7.—Records began in November 1923, computed from measured discharges.

8.—Records began in March 1923, computed from measured discharges.

9. —July to October 1920 not recorded, computed from measured discharges.

10.—1912-1922 computed from White Nile at Malakal minus Sobat at Hillet Doleib.
1923-1926 computed from White Nile above Sobat mouth plus Zeraf at White Nile minus Bahr el Ghazal at Lake No.

11 and 12.—Computed from measured discharges.

13.—August, September, October 1912 and August, September 1913 not recorded, computed from measured discharges.

14.—1916 to July 1917 from general discharge curve. Otherwise from measured discharges.

15.—Computed from measured discharges.

16.—Computed from discharges of River Atbara and of Main Nile at Hassanab, above mouth of River Atbara. River Atbara in 1913 and 1921-1926 from measured discharges, otherwise from general discharge curve. 1912 to January 1922 at Hassanab from general discharge curve but November and December 1914 not recorded. February 1922-1926 at Hassanab from measured discharges.

TABLE III.—SHOWING MINIMUM AND MAXIMUM DISCHARGES OF THE RIVER NILE AT SALIENT POINTS IN ITS COURSE.

SITE.	LOWEST 10-DAY DISCHARGE.		HIGHEST 10-DAY DISCHARGE.		REMARKS.
	m³/sec	Date.	m³/sec	Date.	
Victoria Nile at Ripon Falls ...	326	15– 3–1923	549	22– 1–1903	
Mouth of Victoria Nile at Lake Albert (*i.e.*, below Lake Kioga)	274	23– 3–1923	986	28– 8–1907	See "Lake Plateau Basin of the Nile."
Head of Albert Nile at Lake Albert	235	29– 3–1923	914	13– 5–1909	
Bahr el Gebel at Nimule	324	21 to 31– 3–1923	1,613	1 to 10–11–1917	
Bahr el Gebel at Mongalla	310	11 to 20– 5–1923	2,830	1 to 10–10–1917	
Bahr el Gebel at Bor	308	1 to 31– 3–1923	1,006	1 to 10–10–1916	
Bahr el Gebel at Lake No	242	21 to 30–11–1923	346	21 to 31–10–1924	
Bahr el Ghazal at Lake No ...	5	21 to 31–12–1924	89	1 to 10–10–1926	For Remarks and dates when observations began, see notes to Table II.
Bahr el Zeraf at White Nile ...	54	21 to 31– 3–1922	338	21 to 30– 4–1918	
White Nile upstream Sobat mouth	282	11 to 20– 4–1923	810	11 to 20– 3–1918	
River Sobat at mouth	26	1 to 10– 4–1922	1,248	21 to 28– 2–1918	
White Nile at Malakal	327	1 to 10– 4–1922	1,946	1 to 20– 3–1918	
White Nile at Mogren	—134	21 to 31– 7–1914	2,025	21 to 31–10–1917	
Blue Nile at Khartoum	43	11 to 20– 5–1922	9,234	21 to 30– 9–1917	
Main Nile at Tamaniat	332	1 to 20– 5–1922	10,185	11 to 30– 9–1917	
Main Nile below Atbara...	314	21 to 30– 4–1922 1 to 10– 5–1922	13,732	11 to 20– 8–1916	

CHAPTER II.

REGIME OF THE UPPER NILE.

LAKE ALBERT DISCHARGES.

Considerable advance has been made in our knowledge of the régime of the Bahr el-Gebel and the Sudd Region in late years but there are still many obscure points to be cleared up.

Dr. Hurst on p.p. 54–57 of his " Lake Plateau Basin of the Nile " (part I) has described the method of computing Lake Albert discharges by means of a curve connecting the Mongalla dry weather discharges with Lake gauges observed at Butiaba.

Prior to 1922 these are computed from a gauge discharge curve which gives results that may be as much as 20 per cent in error, though on the average of a number of years the error would be much less. As shown in table IV below, Dr. Hurst concludes that on the average of twelve years, 83 per cent of the Mongalla annual discharge comes from the Lake, falling to 67 per cent in August and September, the remainder being supplied by torrents, as already described. The total average annual discharge of Lake Albert as at Mongalla is worked out as 760 cubic metres per second but the minimum may be much less, as in 1922 it was only 410 cubic metres per second.

If the Lake Albert discharges are computed from the measured data obtained at Mongalla, March 1922–27, the Lake contribution is found to be less than that deduced from the data obtained from the Mongalla gauge-discharge curve. Unfortunately this curve cannot be used to obtain a mean for the series of years 1912–26 as its range is very small, nor would it be sound to comprise in one curve the gauge-discharge computations with the observed discharges, hence the best that can be done at present is to use Dr. Hurst's figures (table IV) to give an idea of the average, but not to use it for particular years, remembering too that the value given for the Lake discharges is probably too high.

When the ratio between the Torrential and Lake supply in the particular year 1925–26 is being dealt with in Chapters III and IV below the deductions will be made from the observed data of the years 1922–27, as the range of the year 1925 falls within the limits of these years, but the deductions for the average year will have to be made from the gauge-discharge data 1912–1923.

TABLE IV.—DISCHARGE OF LAKE ALBERT AS AT MONGALLA MEAN 1912–1923.

Mean monthly Discharges in m3/per second.

Month.	Discharge of Lake Albert as at Mongalla.	Discharge of Torrents as at Mongalla.	Ratio of Lake Discharge to total discharge at Mongalla.
January	790	10	99
February	740	00	100
March	700	00	100
April	680	60	92
May	700	170	80
June	710	190	79
July	730	250	74
August	750	370	67
September	780	380	67
October	820	300	73
November	850	280	82
December	850	30	97
MEAN	760	160	83

TORRENTIAL SUPPLY AT MONGALLA.

The available data seem to indicate that the Lake discharge loses 3 per cent between the Lake and Mongalla as an average for the whole year. This is probably an under-estimate for the distance is 434 kilometres of which about half is described as being flat and swampy, and when these swamp begin to fill losses must be fairly heavy, though masked by the torrential supply which then begins. Moreover the perennial tributaries (Achwa, Unyama, Aswa, Kit and Kaia) contribute something even in February and March, and the figure of 100 per cent in table IV for those months is obviously too high. There are indications that in years of high flood such as 1917 a greater percentage of the Mongalla discharge in flood comes from torrents than in years of ordinary flood, and the total torrential supply is therefore probably much greater in such years than in years of low flood, while individual spates may reach alarming proportions.

The only way of definitely determining how much water leaves the Lake is of course to establish a discharge site at the outlet. It is thought that the bed of the channel near the outlet is fairly constant and therefore after a few years' observations it may be possible to construct an invariable gauge-discharge curve for this site, as at Lake Tana and Lake Victoria. If this were so, it would be possible to determine the Lake discharge since 1904 as Butiaba gauge on the Lake has been regularly recorded since then. Again, then, it is seen that the first point on which more information is urgently required is the true discharge of Lake Albert and hence the amount of the Torrential portion of the Mongalla discharge, with special reference to the magnitude, duration and frequency of spates at Mongalla.

COMPARISON OF MONGALLA AND BOR DISCHARGES.

The next reach of the River, Mongalla to Bor, is also not understood. The discharge at the latter site seldom rises above about 800 cubic metres per second. A total of thirty three discharges was taken at Bor from 1904 to 1924 and since February 1925 regular observations (about three a week) have been recorded. * Those of the discharges prior to 1925 that were taken at the same time approximately as discharges at Mongalla and can therefore be compared with them are shown on table V below.

TABLE V.—COMPARISON OF MONGALLA AND BOR DISCHARGES TAKEN AT CONFORMABLE DATES 1904–1924.

Mongalla Discharges.			Bor Discharges.		
Date.	M³ per second.	Gauge.	Date.	M³ per second.	Gauge.
May 28, 1905...	1,078	12·36	May 31, 1905...	744	11·44
Sept. 26, 1905...	1,263	12·21	Sept. 29, 1905...	732	11·56
March 17, 1906...	932	11·75	March 19, 1906...	721	11·39
May 7, 1908...	527	11·38	May 9, 1908...	666	11·12
July 11, 1908...	1,072	11·98	July 13, 1908...	750	11·32
July 2, 1912...	624	10·98	July 4, 1912...	585	10·60
Aug. 5, 1914...	1,034	12·08			
Aug. 6, 1914...	980	11·78	Aug. 7, 1914...	740	11·17
Oct. 21, 1916...	1,528	12·82			
Oct. 22, 1916...	1,490	12·70	Oct. 28, 1916...	781	11·44
Oct. 23, 1916...	1,492	12·81	Oct. 29, 1916...	787	11·43
Oct. 24, 1916...	1,480	12·80	Oct. 30, 1916...	786	11·44
Oct. 25, 1916...	1,485	12·76	Oct. 31, 1916...	777	11·44
Sept. 4, 1917...	2,287	13·87			
Sept. 8, 1917...	2,695	14·12	Sept. 10, 1917...	885	11·68
April 7, 1923...	390	10·60	April 12, 1923...	299	9·28
May 22, 1923...	694	11·44	May 23, 1923...	530	10·63
June 5, 1923...	561	11·16	June 7, 1923...	639	10·77
MEAN ...	1,136			695	

NOTES :—

(1) Discharge of May 28, 1905 taken at Lado, 15 kilos. above Mongalla.

(2) Discharge of August 5, 1914, October 21, 1916 and September 4, 1917 omitted from mean.

(*) *See* foot note on p. 10.

From a consideration of the above table it will be seen that the loss is sometimes very heavy, the difference of the mean of the fifteen conformable discharges at the two sites being nearly 40 per cent. This is however misleading, for at low levels and when the river is not varying very much the losses are much less. Thus table VI below shows the mean annual discharges for 1925 (eleven months), 1926, and 1927 at Mongalla and Bor and a loss varying from 6 per cent to 17 per cent per annum, the mean being 11 per cent.

TABLE VI.—SHOWING MEAN ANNUAL DISCHARGES AT MONGALLA AND BOR 1925–1926–1927.

Year	Mongalla		Bor		Loss	
	M³ per second.	Mean Gauge.	M³ per second.	Mean Gauge.	M³ per second.	Percentage.
1925	599	11·14	565	10·58	34	6%
1926	786	11·62	653	10·74	133	17%
1927	826	11·68	743	11·18	83	11%

The year 1925 with a loss of only 6 per cent was marked by exceptionally low levels on the Upper Nile and 1927 was also low (loss 11 per cent) while 1926 was a good flood and showed a loss of 17 per cent on the year.

The loss in the flood months, when the flood is good, is very much higher, thus in August 1926 with a mean discharge of 1,172 cubic metres per second at Mongalla, Bor only had 785 cubic metres per second, a loss of 33 per cent, and in October with Mongalla at 1,130 cubic metres per second and Bor at 797 cubic metres per second, the loss was 29 per cent.

Whether such comparisons of discharges at the two sites are valid or not it is not yet possible to say, for there is considerable doubt as to the time of travel of water. The normal time should be two or three days, but this is often exceeded and the year 1926 shows the curious phenomenon that Bor reached a peak about forty days after Mongalla. There seems to be an emptying of the trough when Mongalla gauge and discharge fall which at certain levels is so considerable that the volume thus added to the Bor discharge more than compensates for the decreased quantities reaching Mongalla so that Bor appears to keep steady, or even rise, for some time after Mongalla begins to fall.

Curious phenomena also occur with regard to the River Aliab, which seems to have its off-take above Bor on the left bank and to rejoin the river through several mouths below Bor. Whether any of the Aliab water comes from other sources than the Bahr el Gebel is not known nor whether it is fed only from above Bor, or also by spills below Bor. Sometimes the water flows out of the Bahr el Gebel into the mouths of the Aliab and sometimes on the contrary the flow-out is so great, that if added to the Bor discharge of the Bahr el Gebel, the two are equal, or nearly equal, to the Mongalla discharge. The regime here appears to be very complicated and is not understood, requiring much more investigation.

In general terms one may say that up to about 750 cubic metres per second Bor discharge increases steadily with Mongalla discharge and shows comparatively slight losses while after that figure the losses increase rapidly and it looks as though Mongalla discharge must be maintained at about 1,000 to 1,100 cubic metres per second for two or three weeks before Bor reaches 800 cubic metres per second. To get more than this to Bor requires a very large discharge indeed at Mongalla and any project requiring a greater discharge at Bor would necessitate remodelling the river on this reach. Before anything definite can be said about this a survey (with numerous cross sections) is required of the valley here and a great deal more hydrological information.

The result of such investigation may well be to vitiate the provisional deductions made above and may show that comparatively light remodelling of the Mongalla—Bor reach (closing of spills) would reduce the losses considerably.

LOSSES IN THE SWAMPS.

The next reach of the river from Bor to Lake No is the part where the greatest losses occur, for while it has been shown above that the losses from Mongalla to Bor in the years 1925–26–27 were about 11 per cent of the Mongalla discharge, the losses from Mongalla to the tail of the Swamps was about 44 per cent in those years as is shown in the following table VII.

TABLE VII.—LOSSES IN THE SUDD, MONGALLA TO MALAKAL.

1925–1927. (Millions of m3).

Year.	Mongalla Discharge.	Malakal Swamp Discharge.	Loss.	
			Total.	Per cent.
1925	18,870	12,390	6,480	34
1926	24,850	12,090	12,760	52
1927	26,030	13,520	12,510	48

In studying the losses in the Swamps, the Mongalla data must be used as the Bor data are insufficient, there being practically none prior to 1925.

To determine the swamp losses accurate discharge observations are requisite at each end of the swamp, *i.e.* at Mongalla and in the White Nile at the Zeraf junction, and, further, a knowledge of the time of travel. Table VII above shows the difference in the total discharge at the ends of the swamps in a calendar year, but this is not quite accurate, for no allowance is made for the fact that the water year (minimum to minimum) differs from the calendar year, nor can this necessary correction be made till the time of travel of water through the swamps has been determined.

No information as to this can be deduced from the gauge and discharge observations taken at various places in the swamps because there appears to be no relation between the two, judging from such scattered data as are available.

Prior to October 1926 no station existed in the swamps where discharges were regularly observed, while gauges have only been recorded daily at one place, Shambe. The gauges scattered through the swamps were only read when Irrigation officers happened to pass there on inspection until 1925, since when as already stated they are recorded twice monthly. Scattered discharges and series of discharges at irregular times have been taken and while these reveal many points of interest that require elucidation, they do not furnish sufficient data for that purpose. A discharge site was established in October 1926 at the Zeraf Cuts and regular observations are made there of the discharge of the Bahr el Gebel above and below the Cuts, of the Cuts at head and tail, and of the Zeraf above and below the Cuts. In time, when a reliable mean has been established, valuable information should be deducible from these, by comparison with Bor and Gebel Mouth discharges. As will be shown later, many of the projects for the Sudd Channel contemplate the continued use of the Bahr el Gebel line for part of the water and to enable the conditions under which this is possible to be worked out a relation between discharges and gauges must be established. At present it is not possible to say how much this channel could carry without spilling though it is believed to be about 200 cubic metres per second, but may be less. The levels at which such a discharge would flow are not known.

The whole question of discharge measurements on the Bahr el Gebel in the swamps requires careful consideration, for though there is some evidence to show that the flow in the open channels is the whole forward flow there may be some in the swamps themselves. The most satisfactory method would be to build cross banks right through the swamps at each discharge site, but it is by no means certain that the extra accuracy obtained would be worth the expense. No discharges should be taken at a site unless it is known there are no side channels there, or, if there are side channels, their discharge must also be measured. It would certainly seem advisable to make at least one discharge site with tie banks as suggested and test by experiment whether the discharge thus measured differs appreciably in accuracy from discharges of the main channel where there is no tie bank. A suitable site for such a bank would be either at the Zeraf Cuts, Hillet Nuer or Buffalo Cape.

TIME OF TRAVEL OF WATER THROUGH THE SWAMPS.

In view of the foregoing discussion it seems that the time of travel of water through the swamps can only be determined by comparison of the dates of the maximum and minimum discharges entering and leaving them and unfortunately the available data for determining these have not a high order of accuracy.

The method of ascertaining Mongalla discharge (prior to 1922) from a gauge discharge curve has already been mentioned, as also the probability that computations from this curve may be as much as 20 per cent in error, though the error in an average taken over many years is certainly very much less. Thus while the figure for the mean annual discharge over a long period at Mongalla is probably very close to the truth, the figure for any one year has a greater error and for a lesser period a greater error still. It is however probably possible to state with considerable accuracy the date at which the minimum discharge in any one year occurred, for the gauge-date curve shows when the river was at its lowest and it is practically certain that *in the same season*, in the low stage, a higher gauge indicates a higher discharge, though this is far from certain for different years. Thus if a gauge of say R.L. 10·00 is succeeded the next day by R.L. 10·10 one may be fairly certain that this 10·10 corresponds to a higher discharge than this 10·00, but it by no means follows that 10·10 in one year corresponds to a higher discharge than 10·00 in any other year. Thus the date of lowest discharge in any year can be fixed with fair certainty, and similarly, but not quite so certainly, with the date of highest discharge. The Mongalla gauge curve fluctuates violently in the flood and there may be two or more peaks. It is probable that a gauge of say 12·20 at the beginning of October connotes a higher discharge than say 12·00 at the beginning of September, but the river bed at Mongalla suffers much from erosion and deposition in the flood and the above assumption is by no means certain. However no other criterion of the date of highest discharge is available than the gauge-date curve and this must perforce be used and due caution exercised in drawing deductions.

Measurements of Discharge from the Swamps.

At the other end of the swamps, there is much more dubiety about the exact amount and date of the minimum and maximum discharges, as will appear from an examination of the methods employed in determining them.

Such of the water as passes Mongalla that is not wasted by evaporation issues from the Swamps at their northern boundary by way of the Bahr el Gebel and Bahr el Zeraf, as the amount that perhaps sometimes flows from the Bahr el Gebel through the swamps and Khors into the Bahr el Ghazal and issues from that river is negligible and in any case cannot be determined.

The White Nile in its final state is formed by the waters of the Sobat, Zeraf, Gebel and Ghazal rivers, which may be expressed by the equation :—

$$W = S + Z + G + Gh.$$

Where W = discharge of White Nile below Sobat confluence *i.e.* at Malakal.
S = discharge of River Sobat at mouth.
Z = „ of B. el Zeraf at mouth.
G = „ of Bahr el Gebel at mouth.
Gh. = „ of Bahr el Ghazal at mouth.

If W, S and Z are measured and Gh. assumed then G can be deduced. In the absence of any other observations this method gives a tolerable indication of the amount of the swamp discharge, but it is liable to considerable errors which largely vitiate any precise deductions that it is proposed to draw from the exact size of the discharges so computed.

The gravest of these errors is due to the fact that the method of computation throws a large probable error into the deduced quantity, owing to the mathematical fact that the probable error in any quantity so deduced is equal to the square root of the sum of the errors squared in the other quantities. An example to make this clear is given below, the actual figures for June 1911 being taken, though many other figures are equally striking.

In the middle decade of June 1911 :—

W = 759 cubic metres per second measured.
S = 308 „ „ „ „
Z = 95 „ „ „ „
Gh. = 20 „ „ „ „
G = 633 „ „ „ „

The probable error in each measured discharge is at least + *or* — 5 per cent, *i.e.* 38 in W., 16 in S. and 5 in Z., hence the probable error in G. is :—

$\sqrt{38^2 + 16^2 + 5^2} = 42$ cubic metres per second, which is about 12 per cent of G.

This is the most favourable assumption, for 5 per cent is the probable error in discharges measured by current meters which are regularly rated and do not run too long between ratings. In the early days of investigations in the Sudan this was not understood and current meters were run for years on makers' ratings. Moreover the value of gauge discharge curves was greatly exaggerated, and after a gauge discharge curve had been drawn for a discharge station, this was referred to for determining discharges and only checked by taking two or three discharges a year, the Sobat mouth discharge being only measured fifteen times in the four years 1905–1908, for instance. It is therefore very optimistic to assume that the probable error in the Bahr el Gebel discharge, deduced as above, is only 12 per cent.

Bahr el Gazal Dischrge.

The second source of error is in the assumption that the Bahr el Ghazal discharge is always 20 cubic metres per second which has been mentioned in Chapter I above. In calculating the total contribution that the Bahr el Gazal makes to the White Nile year in, year out, this figure is probably quite close to the truth, but the discharge has been observed to fall to nil in the summer (June 1921) and to reach as much as 89 cubic metres per second in October 1926. It very seldom seems to exceed about 10 cubic metres per second in the summer, and it may be three or four times the assumed amount in the flood. Hence in addition to the probable error of about 12 per cent or 40 cubic metres per second in the Gebel discharge, above described, there is a positive mistake, due to false assumptions, which is probably at least 10 cubic metres per second and may be 20 cubic metres per second in summer, and in flood it may be 50 or 60 cubic metres per second. Thus the error in the swamp discharge, deduced as above, is of the order of 50 cubic metres per second in the low stage and 90 cubic metres per second in the high and as this discharge varies very slowly, the total variation per month being of the order of 20 cubic metres per second, errors of the magnitude above described may easily displace by a month or two the minima and maxima on the discharge-date curves.

The levels of the River Sobat also have some effect for by ponding up the White Nile the losses are increased and the apparent swamp discharge decreased, thus a late peak on the Sobat flood may seem to retard the date of the peak of the swamp discharge.

In 1923 a new method of determining the Swamp discharge was begun by direct measurement of all quantities concerned. To enable this to be done it was necessary to measure the White Nile before its confluence with the Bahr el Zeraf and to measure the Bahr el Ghazal at the mouth. The latter was easy as a clearly defined mouth had been dredged at Lake No in the year 1910 or 1911 and subsidiary exits closed. The White Nile however flows in a wide valley with swampy berms and several subsidiary parallel channels, so to measure its flow it had to be confined to one channel. This was done in 1923 by constructing a tie bank from high ground on the left to the main channel and similarly from high ground on the right, preventing all flow on the berms and in the Khors and concentrating it in the Main Channel. At this place therefore the combined waters of the Bahr el Gebel and Bahr el Ghazal are now measured regularly. A little later the regular measurement of the Bahr el Gebel alone was begun at a site about 3 kilometres upstream of its junction with the Bahr el Ghazal, where there is a patch of high ground on the right bank, the spoil from a test of a dredger carried out in 1911–12, though the left bank is merely papyrus growing in water varying in depth with river levels. Despite the permeable nature of part of the left bank it is probable that the whole forward flow of the Bahr el Gebel is measured in the Main Channel.

At the same time as the observations on the Bahr el Gebel were begun, regular check measurement of the White Nile, immediately below its junction with the Bahr el Ghazal, were also started. These could then be compared with the White Nile discharges observed at the above described tie-bank above the Zeraf junction, 78 kilometres downstream, and give some idea of the losses on this reach.

The following observations are now regularly recorded at the downstream end of the Swamps and should in time furnish precise information of the composition of the White Nile :—

(1) Discharge of the Bahr el Gebel at mouth.

(2) Discharge of the Bahr el Ghazal at mouth.

(3) Discharge of White Nile immediately below junction of Bahr el Gebel and Bahr el Ghazal.

(4) Discharge of White Nile 78 kilometres from (3) immediately above junction with Bahr el Zeraf.

(5) Discharge of Bahr el Zeraf at mouth.

(6) Discharge of River Sobat at mouth.

(7) Discharge of White Nile at Malakal 23 kilometres below confluence of River Sobat.

To the end of 1927, twenty-two years' observations of one kind or another on the Upper Nile are available, of which 18 are of an approximate nature with many assumptions and 4 are more exact, consisting of direct measurements. In using the whole mass of observations to draw deductions on which projects for the control of the river are based, the greatest caution is therefore necessary. Thus deductions as to the total annual loss in the swamps, depending as they do on the mean of many figures, may be received with confidence, but deductions as to the time of occurrence of particular discharges are liable to far graver error and as it is on such deductions that calculations of time of travel of water through the swamps depend the results must be considered as tentative and liable to large amendments (*).

Particular stress is laid on this point of the uncertainty of the data from which time of travel is calculated, for one of the projects for increasing Egypt's water supply which has found much favour, depends on its length.

Table VIII below gives the data from which the calculations are made. The dates given are ten-day periods for it is not feasible to deal with individual discharges and gauges, so the actual observations are always transformed into " 10-day means " for purposes of computation.

The total volume of water passing Mongalla in each year is also given in the table.

The discharge coming from the swamps as determined by observations on the Lake No—Malakal reach of the White Nile either by direct measurements or by the process of deduction above described is called the " Malakal Swamp discharge."

(*) See preface to 3rd Edition.

TABLE VIII.—SHOWING DATES OF OCCURRENCE OF MAXIMA AND MINIMA IN THE BAHR EL GEBEL DISCHARGE AT MONGALLA AND IN THE MALAKAL SWAMP DISCHARGE, 1906–1927.

(Dates given are the 10–day periods in which the maxima and minima occurred).

YEAR.	Mongalla, Total Millions M^3	MAXIMA.			MINIMA.		
		Date at Mongalla.	Date at Malakal.	Interval in 10-day periods.	Date at Mongalla.	Date at Malakal.	Interval in 10-day periods.
1906	38,930	Sept. 11—20	Nov. 21—30	7	March 11—20	May 21—31	7
1907	35,920	Nov. 1—10	Jan. 1—10 1908	6	April 1—10	July 21—31	11
1908	29,810	Aug. 21—31	Sept. 21—30	3	April 11—20	June 11—20	6
1909	31,910	Sept. 21—30	Feb. 1—10 1910	13	March 11—20	June 11—20	9
1910	30,390	Sept. 11—20	Jan. 21—31 1911	13	April 1—10	June 11—20	7
1911	25,270	Sept. 11—20	Dec. 21—31	10	March 1—10	May 1—10	6
1912	33,440	Sept. 11—20	Dec. 21—31	10	March 11—20	June 21—30	10
1913	21,000	July 21—31	Nov. 21—30	12	March 21—31	July 1—10	10
1914	25,520	Nov. 11—20	Jan. 21—31 1915	7	April 21—30	July 11—20	8
1915	27,880	Oct. 1—10	Jan. 1—10 1916	9	March 11—20	June 21—30	10
1916	37,890	Sept. 21—30	Dec. 11—20	7	March 11—20 21—31	June 11—20	8
1917	55,810	Oct. 1—10	March 11—20 1918	16	March 21—31 April 1—10	July 11—20	10
1918	47,130	Jan. 1—10	April 1—10	9	Dec. 21—31	May 11—31 1919	13
1919	31,200	July 21—31	Dec. 11—20	14	March 21—31	Sept. 21—30	18
1920	25,800	Aug. 1—10	Dec. 21—31	14	March 21—31	July 21—31	12
1921	16,620	Oct. 11—20	Dec. 21—31	7	May 1—10	July 1—10	6
1922	15,260	Sept. 1—10	Dec. 21—31	11	Feb. 21—28	June 1—10	10
1923	19,320	Aug. 1—10	Dec. 21—31	14	March 11—20	June 1—10	8
1924	20,450	Nov. 1—10	Jan. 11—20 1925	7	March 21—31	July 1—10	10
1925	18,870	Nov. 21—30	Jan. 1—10 1926	4	March 11—20	June 11—30	10
1926	24,850	Aug. 11—20	Feb. 1—10 1927	17	March 21—31	July 21—31	12
1927	26,030	June 1—10	Aug. 11—20	6	Dec. 21—31	—	—
			Mean ...	9·5		Mean ...	9·6

From the data in this table it is computed that the mean time of travel of water from Mongalla to Malakal is about three and half months with a probable error of one month, whereas if the river were an ordinary water channel the time of travel should be about fifteen to twenty days. The above data indicate no relationship between time of travel and volume of flood, nor between the intervals of maxima and minima in the same year, nor between the season at which the peaks occur and the size of the flood. The great range of the time of travel, varying from one month to six months, seems to show that there are other causes at work than the Mongalla flood alone.

ANNUAL SWAMP LOSSES.*

Using the above time of travel, it is now possible to calculate the swamp losses year by year from 1906 to 1927 from the data of Mongalla and White Nile discharges, and the result is shown in the following table IX. The loss is seen to vary from 4·8 milliards per annum to 39·3 milliards, with a mean of 14·8 milliards. For the shorter period 1912–26 the mean is 13·1 milliards.

* See preface to 3rd Edition.

TABLE IX.—ANNUAL SWAMP LOSSES IN PERIODS CORRESPONDING TO JULY 1ST TO JUNE 30TH AT ASWAN NAMELY MONGALLA : FEBRUARY 7TH TO FEBRUARY 8TH ; MALAKAL : MAY 25TH TO MAY 26TH.

(Totals in Millions of cubic metres per annum.)

YEAR.	MONGALLA DISCHARGE.	SWAMPS DISCHARGE.	LOSSES.	YEAR.	MONGALLA DISCHARGE.	SWAMPS DISCHARGE.	LOSSES.
1906–1907	39,274	13,741	25,533	**1917–1918**	57,741	18,418	39,323
1907–1908	35,095	13,441	21,652	**1918–1919**	44,676	19,556	25,120
1908–1909	29,575	14,802	14,773	**1919–1920**	30,622	16,012	14,610
1909–1910	31,905	16,321	15,584	**1920–1921**	24,898	12,524	12,372
1910–1911	30,067	14,123	15,944	**1921–1922**	16,074	11,140	4,934
1911–1912	24,800	13,208	11,592	**1922–1923**	15,157	10,382	4,775
1912–1913	23,252	13,418	9,834	**1923–1924**	20,111	11,473	8,638
1913–1914	23,218	13,394	9,824	**1924–1925**	20,327	12,893	7,434
1914–1915	25,916	13,874	12,042	**1925–1926**	18,696	12,094	6,602
1915–1916	27,853	13,212	14,641	**1926–1927**	23,844	12,763	13,081
1916–1917	39,340	16,396	22,971				
				Mean.	28,783	13,960	14,823

NOTE.—From 1906 to 1922 Swamps discharges were taken as White Nile at Malakal minus Sobat minus 30 cubic metres per second (for Ghazal). From 1923 to 1927 they were taken as White Nile above Zeraf Mouth plus Zeraf minus Ghazal.

RELATION BETWEEN MONGALLA DISCHARGE AND MALAKAL SWAMPS DISCHARGE.

To know the time of travel of water through the Sudd Region is important, but of equal importance is it to know the quantitative effect produced at the tail of the swamps by a given quantity of water entering at the south end. The earliest attempt in 1910–1913 to improve Egypt's water supply by works on the Upper Nile was propounded as a project " to increase the discharge of the Bahr el Zeraf by so and so much " the underlying assumption being that its normal discharge was known for all conditions of the Upper Nile. This was not the case and as it is obviously unsound to make a project for increasing the flow of a river unless it is known what the flow would have been had there been no project, it is essential to discover some means of ascertaining this and thus establish a criterion for testing the effect of any completed works.

This was done by finding a correlation between the Mongalla discharge and Malakal Swamp discharge. Many relationships were tested for correlation before it was found that the flood discharge at Mongalla, *i.e.* the mean of the three months September, October, and November was closely related to the spring discharge (mean of March, April and May) of the Swamps as at Malakal, the coefficient of correlation being as high as 0·901 in the formula below, and the probable error of a predicted swamp discharge being 5·6 per cent.

$$Y = 0{\cdot}174\ X + 236.$$

Where X = Mean Mongalla discharge in m3/sec. in September, October and November

Y = Mean Malakal Swamp discharge in m3/sec. in following March, April and May.

The following table X gives the data from which the formula is calculated and also the departure of the actual observed discharges from the predictions.

TABLE X.—COMPARISON OF MONGALLA FLOOD DISCHARGES WITH THE MALAKAL SWAMP DISCHARGES IN FOLLOWING SPRING. ACTUAL AND PREDICTED.

(Mean of 3 Months in cubic metres per second).

Year.	Actual Swamps Discharge March, April, May.	Mongalla discharge previous September, October and November.	Predicted Swamps discharge.	Deviation.
	m^3 per sec.	m^3 per sec.	m^3 per sec.	
1906	399	1,292	461	+62
1907	456	1,458	490	+34
1908	417	1,211	447	+30
1909	453	1,044	418	—35
1910	478	1,167	439	—39
1911	666	1,265	456	—10
1912	394	961	403	+ 9
1913	428	923	397	—31
1914	410	714	360	—50
1915	433	1,084	425	— 8
1916	429	1,092	426	— 3
1917	578	1,793	548	—30
1918	629	2,424	658	+29
1919	523	1,327	467	—56
1920	414	1,035	416	+ 2
1921	372	864	366	+14
1922	282	574	336	+54
1923	276	631	346	+70
1924	374	801	375	+ 1
1925	383	746	366	—17
1926	355	621	344	—11
1927	437	1,038	417	—20

Mean Swamp discharge: 427m3/sec.
Probable error : 24 m3/sec. or 5·6 per cent.

The curious thing about this relation is that it connects the Mongalla discharge with the Malakal Swamp discharge at an interval of six instead of about three and a half months which was found to be the time of travel of water from Mongalla to Malakal. The reason for this is not known and though many other intervals were tried for a relation this was undoubtedly the best. It is possible that the first rise at Malakal is due to the rainfall on the Swamps and not to the Mongalla water. The effect of the latter may be masked until the rain ceases in January and February, so that not till March is the undisturbed effect of the Mongalla water felt at Malakal and it is then found to be closely correlated with the discharge of six months previously. The departures from the predictions in the above formula are on the average so small that by its use it should be possible to say with considerable definiteness after the construction of any project for increasing the Malakal Swamp discharge, whether it has in fact done so or not as long as the regime above Mongalla is not altered. It is to be remembered that we are dealing with a mass of natural phenomena producing certain effects at Mongalla and Malakal, of which the preponderant ones are the Lake discharge and Torrential discharge occurring at their natural periods. If these natural phenomena are upset by artificial means, it is not possible to predict with certainty what the effects will be for other phenomena, previously masked or of small importance, may come to have a preponderating effect and upset all predictions based on the observation of undisturbed nature.

NATURE OF FLOW IN THE SWAMPS.

The water that reaches Malakal from Mongalla is water that has come down the channel or channels as fast as possible and is not water that has poured into the swamps from the river as it rises and then returned to it as it falls. The swamps are emphatically not a reservoir where water is stored, but a sink where it is wasted. From the nature of things

there should be a slight flow in the swamps, for in effect they consist of a shallow pond densely overgrown with vegetation but none the less free water, and as this pond is not all at one level there must be a current in it. The important thing to note however is that more water does and must flow into the pond from the river than flows out, as will be shown below.

There are several observable phenomena which demonstrate the fact that there is a flow in the swamps. The most noticeable of these is the peaty colour and taste of the water, especially at high levels. It would seem that this is probably caused by the water flowing over the banks of the main stream and travelling very slowly through, and getting contaminated by, the vegetation till it reaches one of the side channels, which it taints. These side channels later on rejoin the main stream which also becomes tainted. Further the fact that the side channels are at a lower level than the main stream is easily observable in the upper reaches of the swamps—the Atem and Awai swamps—between Bor and Shambe on the east bank and no doubt the same phenomenon occurs in less observable positions in other places. For example, leaving the Bahr el Gebel by Awai Head 1 near Kenisa, water flows at a steep slope from west to east with a stiff current into a lagoon about one kilometre from the river ; this lagoon is also fed on the opposite side by a similar swift stream flowing from east to west from the Atem some 25 kilometres away and is therefore, as it were, in a depression,—a valley whose surface is water thickly overgrown with papyrus through which there are some open water channels. The water flows out of the lagoon at the north end in a clear open water stream which rejoins the Bahr el Gebel some 25 kilometres further on. Obviously, as the whole area is under water, there must be a flow through the papyrus, however slight, as well as through the open water channels, but at all seasons and in all conditions when water flows into the swamps, more flows in than flows out, owing to the losses it sustains from evaporation and transpiration from the swamp growths.

Flow in the swamps parallel to the river has been detected by the use of fluorescene, it only amounted to a velocity of a few millimetres per second and decreased rapidly as the distance from the river increased. Flow in the swamps perpendicular to the course of the river has never, it is believed, been observed or measured but only inferred from the phenomena above described. Sustained research on these points would be very difficult to carry out and its utility is not immediately apparent, for the general and important fact that the swamps are always a source of loss and cannot be considered a reservoir is sufficiently obvious. It was clearly perceived by Mr. C. E. Dupuis, who long ago pointed out that the swamp losses could only be reduced by reducing the evaporation area. This of course can only be done by preventing the water getting into the swamps either by confining the water in its proper channel by means of banks, or by shutting off all or part of the swamps from the water by the same means—two aspects of the same solution.

Rainfall and Evaporation in the Swamps.

Table XI below compares the best available data for rainfall, evaporation and river levels in the main swamps. The rainfall is the mean calculated from eleven stations in and around the swamps, namely Tombe, Bor, Shambe, Meshra el Rek, Fangak, Tonga, Malakal, Abwong, Nasser, Akobo and Pibor Post. The data from the different stations are for varying periods from 1903 to 1927 as the stations were started at different times.

The evaporation figures are the results of one year's observations(*) taken at the Swamps Meteorological Station near the Zeraf Cuts in the heart of the swamps. This station was built in 1926, specifically for the purpose of obtaining statistics of evaporation from a water surface covered with vegetation. Its chief feature is a steel tank, ten square metres by 2·5 metres deep, built into the ground at a distance of about 50 metres from the river's edge, in which papyrus, etc., is grown. It is only approached by a narrow wooden causeway on piles winding through the swamps and is kept to a required water level by pumping from the river's edge through a buried two inch pipe. The ordinary thermometers evaporimeters etc. of a Meteorological station are erected in a standard screen in a clearing at a suitable distance from the tank.

After erection of the tank and screen, nature was allowed to take its course for about six months before observations were begun. By that time, papyrus, etc., were again

(*) Since confirmed as to the total by another year's observations.

flourishing luxuriously in and around the tank, so that in it there is a true sample of swamp confined in such manner that the loss of water in it can be accurately gauged.

The only evaporation statistics previously available were from Piché Evaporimeter readings, but as these instruments have both seasonal and local variations and as the seasonal variations are not similar at different localities, the results are not very reliable. Although the Piché readings are reduced to evaporation from an open water surface by comparison between them and evaporation from tanks of various sizes, yet it is thought that one year's readings of the Sudd tank give a truer idea of swamp evaporation than any Piché readings could furnish. Such comparison as is possible seems to show that the evaporation and transpiration off a surface covered with vegetation is more than twice the evaporation off an open water surface, as deduced from Piché readings.

The river level variations are the means at Shambe River gauge from 1906–1927, this being the only site in the swamps where a gauge has been regularly and continuously recorded.

TABLE XI.—COMPARISON OF CHANGE IN RIVER LEVEL WITH RAINFALL AND EVAPORATION IN THE SWAMPS ALL MEASURED IN CENTIMETRES PER MONTH.

Month.	Evaporation.	Rainfall.	Rainfall minus evaporation.	Change in river levels.
January	14	0	—14	—16
February	12	0	—12	—18
March	13	2	—11	—10
April	16	6	—10	+ 2
May	15	10	— 5	+16
June	12	12	+ 0	+14
July	11	15	+ 4	+10
August	11	18	+ 7	+10
September	11	14	+ 3	+ 8
October	13	8	— 5	— 3
November	11	2	— 9	— 9
December	11	2	— 9	— 4
Total per annum.	150	89	—61	

NOTES :—

Evaporation from Tank at Swamps Meteorological station 1927
Rainfall from 11 stations in and around Swamps 1903–1927
River levels from Shambe Gauge, mean 1906–1927

As the river level data come from one station only and the evaporation data come from one station for one year, any deduction made must be regarded as provisional and treated with much caution, but the following general remarks seem justified. First, the total evaporation per annum is considerably greater than the total rainfall, hence if the swamps depended on local rainfall alone they would dry up very quickly. Secondly, taking the river levels to be representative of swamp levels, when the swamps are rising (April to September) there must obviously be water flowing into them from the river and while they are falling (October to March) as the fall is less or equal to the fall due to evaporation minus rainfall, water is also flowing into them. The months of January and February seem to show an exception to this, but the difference is only a millimetre or two per day, which cannot be considered significant in view of the inadequacy of the data. Moreover the February evaporation figure (the month in which there is the biggest difference) seems doubtful for an examination of the statistics for Malakal, Mongalla and Wau (the three stations round the swamps) shows that in this month the evaporation is normally greater than in January and not less(*).

The evaporation and rainfall statistics therefore support the view that the swamps are a sink and a source of constant loss from the river. Their surfaces are sloping planes inclined down from the river which runs along a ridge and the inclination of these planes varies during the year, with the changing volume in the swamps.

(*) The figures for 1928 show this to be the case also at the tank.

The swamps have the effect of reducing variation in the discharge leaving them, not by any reservoir action but by increasing the percentage losses as the size of the discharge entering them increases. This is clearly shown by the fact that while the maximum annual discharge at Mongalla has been about four times the amount of the minimum, the maximum Swamp discharge has only been about twice the minimum, while the variation between maximum and minimum individual discharges at Mongalla differs even more from the similar variation of the Swamps at Malakal (*see* tables II and III).

Losses on the River Baro.

There is a source of loss of water in the Upper Nile system which was mentioned in chapter 1, namely the Baro River, where heavy spilling into swamps takes place in flood between Gambeila and the mouth of the river Baro at its junction with the River Pibor to form the River Sobat. The few conformable discharges that have been observed at Gambeila and the mouth of the River Baro are given in table XII below :—

Table XII.—Showing all Discharges on the River Baro at conformable dates at Gambeila and the Mouth.

(M3. per second).

Date.	Gambeila.	Mouth.	Difference.
October 1913	617	620	+ 3
Early Sept. 1922 ...	1,015	581	434
Late „ 1922 ...	1,245	628	617
„ „ 1923 ...	967	516	451
„ „ 1924 ...	992	547	445
„ June 1925 ...	700	480	220
Early Oct. 1925 ...	872	560	312
„ „ 1927 ...	1,080	574	506

The loss during September is seen to be of the order of one milliard. Some of it seems to return in October and November, but how much is not known. Hydrologic observations should be begun to determine the season and magnitude of these losses, and surveys to enable a project to be prepared for preventing them. Such a project would probably take the shape of constructing Nile Banks from Gambeila to the Baro mouth and might cost about L.E. 1,000,000 and produce extra water varying from ½ to one milliard per annum. It is to be feared that much of the water saved would be untimely in most years and this is therefore one of the chief points to be settled by the hydrologic studies.

The following two tables XIII and XIV show the mean monthly discharges at various points in the Nile system for the normal of the years 1912–1926 and for the test years 1925–1926, and have been compiled in the same way as tables II and III.

TABLE XIII.—MEAN MONTHLY DISCHARGES AT VARIOUS POINTS IN THE NILE SYSTEM. 1912-1926.

(Million Metres cube per Month).

Normal 1912-1926.

	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Year
Lake Albert (*)	2,062	1,757	1,821	1,711	1,821	1,814	1,902	1,955	1,970	2,143	2,177	2,250	23,383
Mongalla	2,009	1,697	1,784	1,828	2,233	2,188	2,474	2,840	2,825	2,839	2,549	2,269	27,535
Bor	1,604	1,365	1,457	1,497	1,767	1,732	1,874	2,050	1,978	1,971	1,842	1,782	20,919
Swamps at Malakal ...	1,307	1,145	1,235	1,140	1,130	1,086	1,130	1,205	1,244	1,326	1,216	1,286	14,450
Sobat (H. Doleib)	907	537	398	274	438	863	1,330	1,638	1,823	2,062	2,025	1,744	14,039
Malakal (W.N.)	2,219	1,650	1,622	1,401	1,556	1,930	2,450	2,834	3,035	3,345	3,197	3,018	28,287
Mogren (W.N.)	2,465	1,702	1,550	1,420	1,477	1,629	1,558	1,577	2,854	3,772	3,168	2,931	26,103
Khartoum (B.N.)	927	545	430	315	430	1,116	5,061	14,953	14,476	8,297	3,166	1,519	51,335
R. Atbara	—	—	—	—	—	(92)	1,744	5,710	3,667	784	175	(48)	12,185
Halfa	3,794	2,499	2,034	1,617	1,530	1,784	4,591	18,832	21,980	15,424	7,840	5,065	86,993
Aswân D.S.	3,054	2,244	2,028	1,852	2,053	2,560	4,263	16,858	20,704	15,088	7,494	4,181	82,379

(*) This is the discharge of Lake Albert as at Mongalla, computed from a gauge discharge curve for the years 1912-1923.

TABLE XIVa.—MEAN MONTHLY DISCHARGE AT VARIOUS POINTS IN THE NILE SYSTEM.

(Million metres cube per Month.)

1925.

	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Year.
Lake Albert(*)	1,570	1,310	1,405	1,325	1,360	1,295	1,340	1,340	1,305	1,355	1,355	1,470	16,430
Nimule	1,429	1,284	1,385	1,347	1,397	1,379	1,392	1,497	1,443	1,439	1,518	1,499	17,009
Mongalla	1,542	1,296	1,434	1,448	1,672	1,525	1,561	1,863	1,606	1,517	1,750	1,654	18,869
Bor	1,408	1,142	1,242	1,241	1,593	1,432	1,462	1,721	1,675	1,560	1,598	1,664	17,738
Swamps at Malakal ...	1,122	970	1,102	1,033	1,054	986	1,002	1,020	1,005	1,039	1,007	1,048	12,388
Sobat (H. Doleib)	650	226	170	210	467	865	1,316	1,616	1,738	1,975	1,959	1,496	12,688
Malakal (W.N.)...	1,856	1,255	1,292	1,210	1,475	1,829	2,360	2,656	2,746	2,992	2,881	2,593	25,155
Mogren (W.N.)	2,252	1,383	1,230	1,135	1,318	1,432	1,652	1,459	3,177	3,396	2,900	2,589	23,923
Khartoum (B.N.)	906	493	436	304	417	1,261	3,842	13,266	10,719	6,007	2,067	1,115	40,833
River Atbara	—	—	—	—	—	48	1,121	3,950	2,024	466	74	—	7,683
Aswan D.S.	2,498	2,397	1,888	1,716	2,067	2,611	4,171	13,379	16,502	12,275	4,629	3,490	67,623

(*) This is the discharge of Lake Albert as at Mongalla, computed from a gauge-discharge curve for the years 1922-1927.

TABLE XIVb.—MEAN MONTHLY DISCHARGES AT VARIOUS POINTS IN THE NILE SYSTEM.

(Million metres cube per Month.)

1926.

	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Year.
Lake Albert(*)	1,410	1,205	1,295	1,230	1,355	1,385	1,510	1,650	1,730	1,975	2,070	2,210	19,025
Nimule	1,287	1,103	1,230	1,173	1,446	1,391	1,601	2,180	2,042	2,524	2,370	2,336	20,683
Mongalla	1,394	1,184	1,296	1,467	1,876	1,664	2,319	3,131	2,748	3,022	2,397	2,353	24,851
Bor	1,391	1,159	1,290	1,372	1,616	1,607	1,858	2,105	2,011	2,135	2,042	2,060	20,646
Swamps at Malakal ...	1,092	928	1,027	958	969	991	1,009	1,023	972	1,077	1,013	1,030	12,089
Sobat (H. Doleib)	516	264	299	246	637	1,069	1,399	1,680	1,896	2,176	2,143	2,137	14,462
Malakal (W.N.)...	1,646	1,183	1,340	1,238	1,590	1,974	2,341	2,683	2,875	3,323	3,152	3,093	26,447
Mogren (W.N.)	2,149	1,262	1,193	1,140	1,248	1,625	1,513	1,812	2,964	3,784	3,273	2,960	24,923
Khartoum (B.N.)	633	454	507	535	1,093	1,708	5,586	18,904	15,086	7,951	2,442	1,477	56,376
River Atbara	—	—	—	—	—	—	2,022	4,579	3,345	624	142	—	10,712
Aswan D.S.	3,099	2,186	1,644	1,713	2,334	3,151	4,970	18,857	20,529	14,291	7,814	3,549	84,137

(*) *See* note to table XIV *a*.

CHAPTER III.

WATER REQUIREMENTS AND SUPPLIES.

REQUIREMENTS OF EGYPT AT ASWAN.

Egypt's eventual water requirements were discussed at length by Sir Murdoch MacDonald in "Nile Control" (1920) and the conclusion reached that when the country was fully developed its requirements would be fifty milliard cubic metres per annum at Aswân for irrigation plus one and half milliards (in January) for navigation. The International Commission which reported on Sir Murdoch MacDonald's proposals concluded that this estimate for Egypt's future requirements was too low and recommended that a figure of 58 milliard cubic metres should be adopted.

Since that date further calculations have been made based on the volume of water actually supplied to Lower Egypt at the Delta and Zifta Barrages, as the measurements of the discharges at these Barrages has been put on a very accurate basis by Mr. A.D. Butcher, Director of the Hydraulics Section, P.W.M. It is assumed that during the months July to February the water supplied to the irrigated lands is as much as they require and though this is not quite true of the first part of July or the latter part of February, it is a close enough approximation. The mean volume so supplied is calculated for the years 1919–1924, and since the area of perennial cultivation served is known for those years, it is easy to calculate the amount required when development is finished. About 3,100,000 feddans were cultivated in those years while the eventual area of perennial cultivation when Egypt is fully developed will be 7,100,000 feddans of which 4,700,000 feddans in Lower Egypt and 2,400,000 in Upper Egypt. The water duties in Upper Egypt are considered to be 25 per cent higher than those of Lower Egypt, hence the 2,400,000 feddans of Upper Egypt require as much water as 3,000,000 feddans in Lower Egypt, and the total perennial area to be supplied with water eventually is therefore equivalent to 4,700,000 plus 3,000,000=7,700,000 feddans in Lower Egypt. This is nearly 2½ times (248 per cent) as much as the 3,100,000 feddans at present supplied, hence a simple proportion sum will determine how much water will be required in future at the Delta Barrage. But as it is convenient to measure water quantities as at Aswân, an allowance must therefore be made for the ordinary transmission losses from Aswân to the Canal heads at the Asyût and Delta Barrages, and a further 15 per cent is added for this purpose. Thus from the mean figures obtained for the water actually used in the years 1919–1924 for the months July to February at the Delta Barrage, the final figures are worked out for the water that Egypt will require when fully developed, by increasing them by 248 per cent and then adding 15 per cent of the figure so obtained. For the other months, March to June, a different method has been employed, for the Delta Barrage figures cannot be used in the same way, as during these summer months the water supplied is not the most the crops require, but the most there is available, hence to increase the amount by 248 per cent and add a further 15 per cent of that amount for transmission losses, would still leave the eventual area short of the optimum quantity of water.

To arrive at an estimate of the future requirements for the whole year, it is proposed to increase the "Nile Control" estimate for the four months March to June in the same proportion as the Ministry's estimate for the seven months July to February (January excluded) is greater than the "Nile Control" estimate for those months.

In table XV below this has been done. The total of the Ministry's estimate for the seven months is 40·20 milliard cubic metres and of the "Nile Control" estimate 33·80 milliard cubic metres, an increase of almost exactly 20 per cent by which amount the "Nile Control" figures have therefore been increased for the months March to June.

TABLE XV.—EGYPT'S WATER REQUIREMENTS MONTH BY MONTH.
(Milliards of M3.).

MONTH.	Quantity used at Lower Egypt Canal heads for present area.	Quantity at Lower Egypt Canal heads for full development.	Quantity at Aswan for full development.	Nile Control estimate of quantity at Aswan for full development.
February	1·54	3·82	4·40	3·80
March	—	—	4·10	3·40
April	—	—	4·10	3·40
May	—	—	4·90	4·10
June	—	—	6·40	5·30
July	2·25	5·58	6·40	6·80
August	2·55	6·32	7·30	5·70
September	2·47	6·13	7·00	5·30
October	2·46	6·10	7·00	5·70
November	1·54	3·82	4·40	3·40
December	1·31	3·25	3·70	3·10
			59·70	50·00

REQUIREMENTS OF NAVIGATION IN EGYPT.

The Ministry allowed one milliard cubic metres in the future in January for navigation while "Nile Control" allowed one and a half to two milliards. The International Commission of 1925 (Mr. Canten Cremer's) had decided on a discharge of 75 million cubic metres per day as being necessary for navigation, which is about 2¼ milliards per month. It is proposed therefore to allow 2·3 milliards in this month in the new estimate to cover requirements of Irrigation and Navigation in January and also to provide water for washing out the salt water before closing the Rosetta and Damietta Sudds, which in future will almost certainly have to be done at the end of the January closure of canals.

This brings the total of Egypt's requirements in the future up to 62 milliards of metres cube of water annually at Aswân.

REQUIREMENTS OF THE SUDAN.

" Nile Control " estimates the needs of the Sudan by the time Egypt is fully developed to be six milliard cubic metres annually. There seems to be no reason to alter this figure and it will therefore be adopted, thus bringing the total needs of Egypt and the Sudan up to 68 milliards per annum.

WATER SUPPLIES.

Contrasted with these requirements is the following table XVI showing the total discharges that have passed Aswân in recent typical years. The water year is taken from July in one year to June of the next, to include a flood season and the following summer season in the same period.

TABLE XVI.—TOTAL ANNUAL DISCHARGES AT ASWAN.

Years.		Millions of m3.
Lowest Year	1913-1914	42,300
Good Year	1914-1915	89,000
Maximum Year	1917-1918	116,800
Very low ,,	1915-1916 1925-1926	68,200
Average	1912-1926	82,400

(The total discharges at Aswân are taken from downstream of the dam and have been slightly corrected since 1920 owing to the completion of research on the Aswân sluice discharges.)

Standard Year.

It is shown in "Nile Control" that years such as 1915–1916 and 1925–1926 are liable to recur about once in twenty-two years on the average. A year like 1913-1914 has a frequency of only 1 in 240 and it is not proposed to design projects that shall give full protection to agriculture in such years, as this would be highly uneconomical for obvious reasons. If such a year recurs in the future its effect will be to leave the then existing reservoirs only partially filled and the extent of the deficit will be known with close accuracy by about October. The Government would therefore have plenty of time to warn cultivators that the area of crop in the following summer season must be reduced. This is the sort of risk that every agricultural community must face only too frequently while lucky Egypt only has to do so once in about two centuries.

It is considered however that any project for the complete development of Egypt must afford absolute protection against such years as 1915–1916, which occur fairly often. This was the standard year taken in "Nile Control" for testing the effect of projects, and it is proposed now to substitute 1925–26 for 1915–16 as both have exactly the same total discharge at Aswân but knowledge of Upper Nile discharges and gauges is far wider and more accurate for 1925–26 than for the earlier year.

Comparison of Requirements and Supplies, Standard Year.

Table XVII below shows in parallel columns the eventual water requirements of Egypt and the Sudan and the Aswân discharges month by month for these two years. The Sudan requirements are not corrected to allow for losses to Aswân.

Table XVII.—Comparison of Requirements and Supplies at Aswan
Standard Year 1925–1926.
(Millions of M^3).

Month.	Requirements.			Supplies at Aswân.	Excess or Deficit of Supplies.
	Egypt.	Sudan.	Total.		
July	6,400	340	6,740	3,780	—2,960
August	7,300	750	8,050	13,300	+5,250
September	7,000	720	7,720	16,500	+8,780
October	7,000	750	7,750	12,400	+4,650
November	4,400	720	5,120	4,630	— 490
December	3,700	720	4,420	3,490	— 930
January	2,300	590	2,890	3,100	+ 210
February	4,400	430	4,830	2,190	—2,840
March	4,100	470	4,570	1,640	—2,930
April	4,100	300	4,400	1,710	—2,690
May	4,900	110	5,010	2,330	—2,680
June	6,400	100	6,500	3,150	—3,350
Totals	62,000	6,000	68,000	68,220	—

Effect of a dam at Gebel Aulia.

There is a considerable excess of supplies (over 18 milliard cubic metres) in flood (August to October) and a deficit during the rest of the year, except January, the month of closure of canals in Egypt, when there is a trifling surplus. The excess water cannot be stored on the Main Nile as it is full of silt, but the part of it that comes from the White Nile, which is always free of silt, could be stored in a reservoir at Gebel Aulia, leaving only the

Blue Nile and Atbara water to come on to Aswân, and part of the Blue Nile water could have been stored at Lake Tana. The time of travel of water from Khartoum to Aswân may be taken as about half a month, hence the Aswân discharge could have been diminished during August to October by impounding the White Nile water at Khartoum from mid-July to mid-October. This would have left at Aswân only the water of the Blue Nile and Atbara plus any gains from seepage, emptying of basins etc., and the following table XVIII shows that these two rivers alone would have had an excess of about 12·7 milliards of supplies over requirements at Aswân in the three flood months of 1925.

TABLE XVIII.—COMPARISON OF DISCHARGES OF THE BLUE NILE AND ATBARA AT ASWÂN IN FLOOD 1925 WITH FINAL REQUIREMENTS OF EGYPT AND THE SUDAN. (Millions of M³).

Month, Aswan Date.	White Nile at Khartoum*	White Nile at Aswan.	Supplies at Aswan.	B. Nile, Atbara & gains at Aswan.	Requirements at Aswan.	Excess at Aswan.
August	1,800	1,450	13,300	11,850	8,050	3,800
September	2,500	2,000	16,500	14,500	7,720	6,780
October	3,100	2,500	12,400	9,900	7,750	2,150
TOTAL	7,400	5,950	42,200	36,250	23,520	12,730

EFFECT OF RESERVOIR AT LAKE TANA.

The Egyptian Mission at Lake Tana proved that only a small proportion of the water of the Blue Nile comes from the Lake. Discharges were measured from August 1920 to April 1924, while gauges alone were read till December 1925. As the outfall of the Blue Nile from Lake Tana is over rock the gauges give an invariable measure of the discharge, so the discharges deduced from the gauges are nearly as reliable as the measured discharges.

The mean of each month for the whole period is given in table XIX below and also the figures for 1925. The time of water travel from Lake Tana to Aswân is about one month, hence the July—September discharge at Lake Tana corresponds to the August—October discharge at Aswân, the period during which water is in excess of requirements at that site. The loss en route to Aswân is taken as 30 per cent.

TABLE XIX.—DISCHARGE OF THE BLUE NILE AT LAKE TANA 1925 AND MEAN 1920–1926.

MONTH.	MEAN DISCHARGES 1920–25.		DISCHARGES 1925.	
	Mean M³/sec.	Total in million M³.	Mean M³/sec.	Total in million M³.
January	91	245	106	285
February	59	144	68	165
March	36	97	43	115
April	30	52	23	60
May	11	29	13	34
June	8	21	8	20
July	28	76	16	42
August	178	478	132	354
September	376	975	247	640
October	325	870	217	582
November	214	554	142	369
December	136	365	92	248
Mean Annual... ...	126	3,886†	92	2,924

* Half month earlier than Aswan dates.

† 1920 not included.

If now a dam is constructed at Lake Tana the flow of the Blue Nile could be reduced by 1,036 millions cubic metres at the Lake outlet from July to September in a year like 1925, equivalent to about 0·7 milliard cubic metres at Aswân between August and October, thus reducing the excess there in those months from about 12·7 to about 12·0 milliards.

It is proposed to use the term "timely" for the water that enters the Main Nile at times when it can (in future) be used directly for irrigation or for storage on that river, while "untimely" will refer to water that cannot be so used.

Thus the Blue Nile and Atbara supplies that reach Aswân from August to October are largely untimely, and the White Nile water that passes Khartoum from mid July, roughly, till mid October is also untimely and must be stored on the White Nile if it is to be used at all. It will be seen later that a considerable amount of the Upper Nile Water is untimely too.

The untimely water of the White Nile amounted in 1925 to about 7·4 milliards measured at Khartoum equal to about 5·9 milliards at Aswân. If this had been stored at Gebel Aulia, there would have been a loss of about 3·6 milliards in evaporation and transmission to Aswân, where 3·8 timely milliards would have arrived instead of the 5·9 untimely milliards that actually did arrive in 1925.

The following balance sheet, Table XX, shows the distribution of the water when a 1925–26 year recurs in the future.

TABLE XX.—BALANCE SHEET OF DISPOSAL OF SUPPLIES AT ASWAN IN A 1925-1926 YEAR.

(Milliards of M3.).

		Milliards.
Timely flow directly employed in July and from November to June		26·00
Portion of untimely flow, August to October, directly employed		23·50
Portion of untimely flow stored in Lake Tana		0·70
Portion of untimely flow stored in White Nile :		
	=5·9 M. at Aswan.	
	=7·4 M. at G.A.	
Loss at Gebel Aulia and in river from G.A. to Aswan	3·6 M.	
Reaches Aswan at timely period	3·8 M.	3·80
Total usefully employed		54·00
Excess in flood, lost to sea...		12·10
Nett loss through using Gebel Aulia...		2·10
TOTAL...		68·20

DEFICIT IN STANDARD YEAR.

Now as Egypt and the Sudan's requirements are 68 milliards and only 54 milliards of the Nile's flow can be used in 1925–26, there will be a deficit of 14·0 milliards and if there were no reservoir at Gebel Aulia, this would be increased to 17·8 milliards.

EFFECT OF A HIGHER DAM AT ASWAN.

There are two means by which this deficit of 14·0 milliards can be reduced, the first by catching more of the water at Aswân in a higher Aswân Dam, and the second by stopping the waste in the Sudd Region. The amount which could be safely held in a higher Aswân without danger from silt is not yet known definitely, but can certainly not exceed 2½ milliards, as that is the maximum additional capacity of a heightened Aswân, so that there would still be a deficit of 14—2·5=11·5 milliards approximately.

STOPPING WASTE IN THE SUDD REGION.

The waste in the Sudd Region amounted in 1925–26 during the period corresponding to July 1, 1925—June 30, 1926, at Aswân to 6·6 milliards. Even if the whole of this could

be impounded in Lake Albert (which is not the case) only about 60 per cent or 4·0 milliards would reach Aswân, when it is eventually released, to meet a deficit of 11·5 milliards, as the rest would be lost in transmission. But the problem is more complicated than this for the Mongalla discharge comes partly from Lake Albert and partly from Torrents, and the Torrential supply can none of it be stored in Lake Albert, while much of it will be untimely in the future when the Sudd Channel is built to lead it to Khartoum in a month from Mongalla. Hence if it is to be used at all much of it must be stored at Gebel Aulia till a suitable season, and necessarily suffer heavy losses there from evaporation, meanwhile.

Table XXIII below (Chapter IV) gives the Mongalla discharge in 1925–26 and in a normal year, divided into the Lake and Torrential components. It will be remembered that this division is an estimate based on very scanty data especially as regards the normal year and it seems probable that the Lake supply is less and the Torrential supply greater than that shown.

The untimely period at Mongalla in the future if a 1925–26 year recurs will be about June 15 to September 15 and the table shows that the Torrential supply during this period is of negligible proportions. Even when augmented by the navigation water, the supply reaching Malakal will be less than at present during the untimely period, while during the rest of the year the torrents are small compared with the deficiency in Egypt and can be passed straight on for direct use on the land. The quantities to be dealt with are so small and our data are so vague that it is not worth while going into detailed calculations differentiating the Torrents from the Lake supply for 1925–1926. This question, as also that of navigation water, will be discussed in greater detail in Chapter IV below but the foregoing remarks suffice to show that in 1925–1926, there will be deficiency in supply for Egypt and the Sudan of about 8·0 or perhaps even 10 milliards, even after the most careful conservation and distribution of all the available water, with the exception of the flood discharge of the River Baro and the waters of the Bahr el Ghazal basin. Perhaps one or two extra milliard cubic metres might be obtained from the River Baro, but whether anything can be got from the Bahr el Ghazal and if so how much, it is quite impossible to say at present.

The possibilities of over-year storage must therefore now be considered, that is to say, suppose the waste in the Sudd is stopped every year, would enough be left over from years of good supply to make good the deficiency in years such as 1925–26, if it could be stored from year to year in some suitable reservoir.

Comparison of Requirements and Supplies, Average Year.

Table XXI below compares supplies and requirements at Aswân in an average year, for the period 1912 to 1926.

Table XXI.—Comparison of Requirements and Supplies at Aswan, Average Year. 1912—1926, (Millions of M³).

Month.	Requirements at Aswan.			Supplies at Aswan.	Excess or deficit of supplies
	Egypt.	Sudan.	Total.		
July	6,400	340	6,740	4,260	— 2,480
August	7,300	750	8,050	16,860	+ 8,810
September	7,000	720	7,720	20,700	+12,980
October	7,000	750	7,750	15,100	+ 7,350
November	4,400	720	5,120	7,500	+ 2,380
December	3,700	720	4,420	4,200	— 220
January	2,300	590	2,890	3,050	+ 160
February	4,400	430	4,830	2,240	— 2,500
March	4,100	470	4,570	2,030	— 2,540
April	4,100	300	4,400	1,850	— 2,550
May	4,400	110	5,010	2,050	— 2,960
June	6,400	100	6,500	2,560	— 2,940
Total	62,000	6,000	68,000	82,400	—

In an average year, there is considerable excess (over 31 milliards) from August to November and a deficit during the rest of the year of over 17 milliards.

The comparison between requirements and supplies from the Blue Nile and Atbara is made in Table XXII and shows that the unusable excess from these sources must be 23·4 milliards, less the amount stored in Lake Tana, which would be equivalent to about one milliard at Aswân in a normal year, reducing the above excess to 22·4 milliards.

TABLE XXII.—COMPARISON OF SUPPLIES FROM BLUE NILE AND RIVER ATBARA WITH EVENTUAL REQUIREMENTS IN AN AVERAGE YEAR, AUGUST TO SEPTEMBER.

1912—1926

(Millions of M^3).

Month.	White Nile. at Khartoum.	White Nile. at Aswân	Whole Nile at Aswân.	B.N., Atbara and gains at Aswân.	Required at Aswân.	Excess of B.N. and Atbara at Aswân.
July	1,560	—	—	—	—	—
August	1,580	1,260	16,860	15,600	8,050	7,550
September	2,850	1,780	20,700	18,920	7,720	11,200
October	3,770	2,650	15.090	12,440	7,750	4,690
	7,100	5,690	52,630	46,960	23,520	23,440

The amount stored in Gebel Aulia would be 7·1 milliards, (equal to 5·7 milliards at Aswân) and of this about 3·6 milliards would reach Aswân eventually at a timely period, making the nett loss due to the use of Gebel Aulia Reservoir 2·1 milliards.

In a normal year there is an excess of about 2·5 milliards in November and January, which could however probably be stored in a heightened Aswân Reservoir and used at a timely period, hence the total loss in such a year would be 24·5 milliards, the sum of the unusable excess (lost to sea) and the loss due to using Gebel Aulia, if Gebel Aulia, Tana and a heightened Aswân Reservoir were in use. The total supply being 82·4 milliards the amount that could be used is therefore 57·9 milliards against requirements of 68 milliards leaving a deficit of 10·1 milliards to be supplied by stopping waste in the Sudd Region.

The argument and calculations for arriving at the economy to be effected by the future regime in the Sudd are set out in Chapter IV, but the summarised result may be given here, as follows :—

DEFICIT IN AVERAGE YEAR.

The loss between Mongalla and Malakal at present in a normal year (1912–1926) is 13·1 milliard cubic metres out of a total of 27·6 milliard cubic metres reaching Mongalla. Allowance has already been made above for the effect of a reservoir at Gebel Aulia and a higher reservoir at Aswân, which will be such that out of the total of 14·5 milliards reaching Malakal 9·1 milliards can be used in Egypt instead of 6·7 milliards as at present. The further effect of Lake Albert and the Sudd Channel will be to increase this to 14·0 milliards *i.e.* by 4·9 milliards or 37 per cent of the present Sudd waste of 13·1 milliards. Thus in an average year there will still be a deficit of 10·1—4·9=5·2 milliards.

It seems therefore that in an ordinary very low year (1925–26) there will be a deficiency of about 8 to 10 milliards and in an average year of about 5 milliards of cubic metres at Aswân.

As there is a deficiency of supply to requirements in an average year there is no possibility of getting over-year storage to meet it, for all that can be stored in a series of years is the difference between average supplies and average requirements. Over-year storage will however be required, for in some years there is a great excess and this must be saved to meet very low years, provided it will not be wasted in evaporation during storage. The question of the possible amount of this over-year storage and the consequently necessary capacity of the Lake Albert Reservoir will be discussed in Chapter IV but meanwhile it is clear that *without additional sources of supply Egypt cannot be fully developed*, even though economies in use of water may be effected by better distribution.

The investigation of the possible quantities of water to be derived from controlling Lake Victoria and the Victoria Nile, the River Baro and the Bahr el Ghazal basin therefore requires to be taken in hand without delay.

CHAPTER IV.

LAKE ALBERT RESERVOIR AND THE FUTURE REGIME OF THE UPPER NILE WITH A RESERVOIR AT GEBEL AULIA AND A HIGHER RESERVOIR AT ASWAN.

Reservoir at Lake Albert.

Sir William Garstin was the first to point out that Lake Albert formed an ideal site for a reservoir in which the water that now pours into the swamps could be stored and later released in controlled quantities in accordance with Egypt's requirements. A necessary corollary of such a reservoir would be a channel through or round the swamps, in which the water could flow without spilling and undue waste. Such a channel is usually referred to as the " Sudd Channel " and the discussion of possible lines with the problems that arise are dealt with below in Chapter V.

The construction of a dam at Lake Albert and of the Sudd Channel seemed to offer a complete solution of Egypt's water difficulties, as her future requirements had not then been estimated and it was thought that the Lake portion of the Mongalla discharge, if properly conserved would suffice for all her needs. Whether the Torrential portion was thought to be negligible or unnecessary is not known, as it appears never to have been considered. The discussions in Chapter II and III of this Note have shown first that even careful conservation of the whole of the Mongalla discharge will not meet all Egypt's future needs in average years, and second that the torrents provide a high proportion of the Mongalla discharge, especially in those months when the whole of this discharge is superfluous for Egypt and should be stored for use later in the same year or in subsequent years.

Navigation Water and Torrential Supplies.

A further complication is added by the necessity of providing for navigation on the Bahr el Gebel the whole year round. This river is the only line of communication with the Southern Sudan and will always be of importance, even if railways and road communication are opened in the future. The Belgian Congo and Uganda Lake ports connect by water with Nimule, thence by road to Rejaf and thence again by water to Khartoum, while there is a good motor road with increasing traffic from Rejaf to Aba in the Belgian Congo. Any project therefore that would involve suspension of navigation for even part of the year is impracticable and cannot be considered.

The Torrential supply and the navigation water must be conserved equally with the Lake supply, unless they would arrive in Egypt at a time when they could be used for irrigation, other sources being deficient. Now the torrents begin in April and end in November, being at their maximum in August and September, and the time of travel from Mongalla to Aswân via the Sudd Channel will be about seven weeks. The torrents would therefore arrive in Egypt between July and January and be at their maximum in October and November, and as there is and always will be more water in Egypt than is required in August to October from the Blue Nile and Atbara, a large part of these torrents (and the navigation water) would run to waste in the sea. A reservoir in which they can be stored is therefore essential and can only be found either on the lower reaches of the White Nile or on the Main Nile.

Such part of the water as reaches Khartoum while the Main Nile is full of silt must be stored in a reservoir on the White Nile, Gebel Aulia, while the later supply, when the Nile is clear, could be stored at Aswân, if that reservoir were not already full.

Effect in Flood.

It has already been shown in Chapter III that a reservoir at Gebel Aulia is necessary to store the White Nile water in the flood, which would otherwise run to sea, and the above discussion shows that its further function will be to store the untimely part of the torrential supply and the navigation water. The revolution in the Nile regime to be caused by the Lake Albert Dam and the Sudd Channel will have an effect not only on Egypt's low stage supply, but also on the flood. During this season not more water, but less, is required

in Egypt especially in years of high flood on the Blue Nile, whose volume may endanger life and property in Lower Egypt. The correlation between high floods on the Blue Nile and White Nile systems is slight, but this is not to say that high floods will never occur in the same year on both rivers, for the year 1917 is an example to the contrary. The Blue Nile flood of that year was very high but not the maximum recorded, whereas the White Nile flood was of extra-ordinary volume, the whole of the Southern Sudan being under water for weeks and even months.

The effect of the Sudd Channel will be to increase the volume of water reaching Khartoum in the flood months, as is shown by the figures below, and though this increase may not be important on the average yet in some years it may cause damage. These possibilities must be considered and means of preventing them provided.

It is interesting to observe in studying the published and departmental reports on the Upper Nile problem, how this question of protecting Egypt against high floods has fallen into the background. The danger seems constantly to have been before Sir William Garstin's mind but receded into the background in succeeding discussions. The Reservoir at Gebel Aulia was first put forward as a flood protection scheme, but that part of its proposed functions is now (1925 Project) abandoned and the possibility or even probability of increasing the danger from high floods by works on the Upper Nile is to a large extent neglected. The last really dangerous flood occurred in Egypt in 1892 and is not remembered by the present generation of Irrigation Engineers, and " out of sight, out of mind " applies very aptly here. It is said that Nile banks have now been so strengthened and improved that the danger is greatly lessened, but against this is to be placed the fact that large basin areas in Upper Egypt have been converted since 1892 and the remainder will be converted when Egypt is fully developed. These basins used to serve as a flood escape, which is now no longer available, and flood levels in Lower Egypt are therefore bound to be higher, if a 1892 flood recurs in the future than they actually were in 1892. In addition it must be remembered that for a great many years there has been practically no flow in the Rosetta and Damietta branches in summer and therefore no opportunity for clear water scour of the river bed with the consequence that, very likely, floods now flow at higher levels than floods of the same volumes used to in the past.

Whether Egypt can afford to risk piling anything more on to the top of an 1892 flood, unreduced by feeding basins, is a matter that requires the earnest consideration of the highest authority.

It is clear that the Torrential portion of the Mongalla discharge must be considered from two points of view. First how can it be conserved in years of low and average supply, second how can it be dealt with in high years to avoid endangering Nile banks and damaging agriculture in Lower Egypt. Bound up with the first consideration is the question of how to deal with the navigation water necessarily to be released from Lake Albert during the months when Egypt does not require irrigation water from this source.

The necessary amount of this navigation water must be guessed and is probably about 400 cubic metres per second for it is known that about 300 cubic metres per second is far too little. The latter was the approximate discharge flowing in the Albert Nile in the spring of 1923 and at that time through navigation on the Lake Albert—Nimule reach had to be suspended and trans-shipment made in small boats over long distances, while on the Rejaf-Bor reach navigation was exceedingly difficult. The Torrential supply of course increases gradually from the Lake to Mongalla, but in the first reach, immediately below the dam, it must probably be nil and this is one of the shallowest and most difficult reaches for navigation. Future investigations may show that when there are early heavy rains less is required, or the remodelling of this reach (which will be shown to be needed) may be designed so as to reduce the minimum requirements of navigation, but for the present it must be assumed that about 400 cubic metres per second will have to be released continuously from Lake Albert.

The data for the discussion of this question are given in table XXIII below in which the figures for the normal year 1912–26 are computed from the mean Lake Gauges for that period and the gauge discharge curve for the years 1912–23, as explained in Chapter II The Lake supply is probably less than that shown. For the years 1925 and 1926 the figures are taken from a gauge discharge curve for those years and are probably more accurate, though the estimate of the Lake supply is still too large, in the winter at any rate, but such slight discrepancies are inevitable in using gauge discharge curves.

The times of travel may be taken, for a first approximation, as half months each from the Lake to Mongalla, Mongalla to Malakal via the Sudd Channel, Malakal to Khartoum (Gebel Aulia) and Khartoum to Aswân, while table XXIV shows the transmission losses adopted as being likely to occur in the future from the Lake to Aswân via the Sudd Channel.

TABLE XXIII.—MONGALLA DISCHARGE, DIVIDED INTO LAKE AND TORRENTIAL SUPPLY FOR 1925, 1926 AND MEAN OF 1912–1926.

(Millions of M3. per month).

MONTH.	1925			1926.			Normal 1912-1926.		
	Lake.	Torrents.	Total.	Lake.	Torrents.	Total.	Lake.	Torrents.	Total.
January	1,570	—	1,542	1,410	—	1,394	2,060	—	2,010
February ...	1.310	—	1,297	1,205	—	1,184	1,760	—	1,700
March	1,405	29	1,424	1,295	1	1,296	1,820	—	1,780
April	1,325	123	1,448	1,230	237	1,467	1,710	120	1,830
May	1,360	312	1,672	1,355	521	1,876	1,820	410	2,230
June	1.295	230	1,525	1,385	279	1,664	1,810	380	2.190
July	1,340	221	1,561	1,510	809	2,319	1,900	570	2,470
August	1,340	523	1.863	1,650	1,481	3.131	1,960	880	2,840
September ...	1,305	301	1,605	1,730	1,018	2,748	1,970	860	2,830
October	1,355	162	1,517	1,975	1,047	3,022	2,140	700	2,840
November ...	1,355	395	1,750	2,070	327	2,397	2,180	370	2,550
December ...	1,470	184	1,654	2,210	143	2,353	2,250	20	2,270
TOTALS	16,430	2,480	18,869	19,025	5,863	24,851	23,380	4,310	27,340

TABLE XXIV.—TABLE OF LOSSES.

(A) Going downstream showing percentages of Water passing upstream Station that reach downstream Station. (*Via* Sudd Channel).

Lake Albert	100	—	—	—
Mongalla	95	100	—	—
Malakal	80	85	100	—
Khartoum	70	75	90	100
Aswan	50	60	70	80

(B) Going upstream showing percentage increase required at upstream station to produce a certain discharge at the downstream station. (*Via* Sudd Channel).

Aswân	100	—	—	—
Khartoum	140	100	—	—
Malakal	160	115	100	—
Mongalla	190	135	120	100
Lake Albert	200	140	125	105

DISPOSAL OF TORRENTS IN STANDARD YEAR.

In a 1925–26 year the untimely period at Aswân will be three months, August to October, corresponding to June 15—September 15 at Mongalla.

Navigation water during this period will be one milliard per month at the Lake which is reduced to 0·80 milliard per month, or 2·4 milliards for three months from July, at Malakal.

The untimely torrents amounted to 1·01 milliards at Mongalla equivalent to 0·85 milliards at Malakal.

Thus in such a year in future the swamp discharge at Malakal from July 1 to October 1 will be 1·65 milliards as compared with the present 3·03 milliards, a decrease of about 1·4 milliards.

The conservation of the navigation water and torrential supply in a low year therefore presents no difficulties, as it will be less than the present Swamp discharge and can either be stored in Gebel Aulia or used direct on the land. It is interesting to note in table XXIII that the torrential discharge in August 1926 was about 1½ milliards, 47 per cent of the total Mongalla discharge.

Disposal of Torrents in Average Year.

The effect the Lake Albert dam and the Sudd Channel would have in a normal year requires more detailed working out as follows :

The total Mongalla discharge in a normal year is 27·6 milliards, the Lake contribution being 23·3 milliards at Mongalla equivalent to 24·5 milliards issuing from the Lake. The untimely period in such a year is the four months August to November inclusive at Aswân corresponding to June to September at the Lake, and during these four months one milliard per month would have to be released as navigation water. The remaining 20·5 milliards of the Lake flow could be stored and distributed as required by Egypt, and half of it would be lost in transmission so that 10·25 milliards would arrive at Aswân at timely periods.

The torrential supply in such a year is 4·3 milliards at Mongalla, of which 2·9 milliards are untimely (June 15 to September 15) and 1·4 milliards timely. The untimely portion will be dealt with together with the navigation water, while the timely portion passes straight on to Aswân, where 60 per cent of it or 0·8 milliard arrives.

The navigation water, 4 milliards, is reduced to 3·2 milliards by the time it reaches Malakal, and the 2·9 milliards of untimely torrents become 2·5 milliards there, making a total of 5·7 milliards arriving at Malakal from the Sudd Channel during the untimely period (July–October) as compared with 4·9 milliards arriving there in such a year from the Swamps at present. Thus the effect of the Sudd Channel in a normal year is to increase the untimely discharge by 0·8 milliards (5·7 minus 4·9) at Malakal or about 0·7 milliards at Gebel Aulia, where it must be stored for a time if any of it is be used.

Suppose the whole above untimely 5·7 milliards can be stored, the amount that would arrive at Aswân eventually is only about 2·7 milliards. The whole of the Mongalla discharge is now accounted for and the amount that would reach Aswân is as follow :

Part of Lake discharge stored at Lake Albert and released as required, of which 50 per cent reaches Aswân	10·25
Timely Torrents at Mongalla of which 60 per cent reaches Aswân ...	0·80
Navigation water and untimely torrents reaching Aswân after being stored in Gebel Aulia	2·70
Total	13·75
Say	14·00

Total Effect of Upper Nile Works.

Thus by the full use of the whole series of works about 14 milliards of the 27·6 milliards that now pass Mongalla in an average year can be made available for use in Egypt.

At present out of these 27·6 milliards, 14·5 milliards reach Malakal, of which 4·9 milliards are untimely and wasted to sea, while 9·6 milliards are timely and useful, but reduced to 6·7 milliards by transmission losses before they reach Aswân.

If there were a reservoir at Gebel Aulia, these untimely 4·9 milliards could be stored and 2·3 milliards or 2·4 milliards would eventually reach Aswân, bringing the total quantity of Upper Nile water usefully employed in Egypt up to about 9·1 milliards.

Lake Albert Dam and Sudd Channel would increase this to 14·0 milliards, as shown above, or by 4·9 milliards out of the present Sudd waste of 13·1 milliards, *i.e.* by 37 per cent of that waste. These results are tabulated below (Table XXV).

TABLE XXV.—SHOWING EFFECT OF UPPER NILE WORKS ON ASWAN DISCHARGE.
AVERAGE YEAR 1912–1926. (Milliards of M3.).

PERIOD.	MONGALLA DISCHARGE: 27.6 MILLIARDS.				
	Wasted in Sudd.	Reaches Malakal.	Reaches Aswan (timely).	LOSS.	
				TOTAL.	Percentage of Mongalla.
At Present	13·1	14·5	6·7	20·9	76°/o
After Gebel Aulia Dam is built	13·1	14·5	9·1	18·5	67°/o
After Lake Albert Dam and Sudd Channel are built ...	—	23·4	14·0	13·6	49°/o

It should be noted that one effect of the Sudd Channel will be to increase the untimely discharge of the Swamps reaching Gebel Aulia by about 0·7 milliards in a normal year.

EFFECT OF TORRENTS IN YEARS OF HIGH FLOOD.

The discussion of how to deal with torrents in a year of high supply is necessarily lacking in precision owing to the absence of reliable data. All that can be done is to point out that a danger exists and provide means to deal with it, when its magnitude can be determined. It is caused by the torrential portion of the Mongalla discharge which, through the Sudd Channel, might reach Egypt at a time when the Nile levels are still very high from the Blue Nile supply and thus either raise the levels in Lower Egypt alarmingly or lengthen the period of high levels or both. Either result would increase the danger of breaching a Nile bank and thus causing a national catastrophe of the first order, but even though this is not likely to occur the lengthening of the period of high flood levels will raise the sub-soil water levels and have a definitely injurious effect on agriculture.

Some indication of the order of magnitude of the danger can be found in a consideration of the available figures for the year 1917, when exceptionally high discharges occurred in the Upper Nile and very high ones on the Blue Nile. It has been shown in Table IV (Chapter II) that in August and September the torrential portion of the Mongalla discharge is about 33 per cent of the whole on the average. In high years it is more and there is reason to think that in 1917 it may have been about 40 per cent, that is to say that the Swamp discharge at Malakal might have been increased from the actual 500 cubic metres per second roughly to about 1,000 cubic metres per second (allowing for the navigation water as well as the torrents) during August and to 1,200 cubic metres per second in September. This would be equivalent to an increase of about 400 to 500 cubic metres per second at Aswân and would thus lengthen the period of high levels in Lower Egypt, unless the extra water could be stored at Gebel Aulia, temporarily at any rate.

If the mean volume of the torrents at Mongalla is about 1,000 cubic metres per second, quite certainly occasional spates would reach a magnitude of 2,000 cubic metres per second or more. Such spates would be damped down very considerably and might entirely disappear before reaching Egypt, but if they happened to coincide with spates on the Sobat or Blue Nile or Atbara, they might cause considerable damage. All that can be said is that there is danger of disaster from spates, though perhaps not very great, and the certainty of damage due to lengthening the period of high levels.

ALTERNATIVE FLOOD ESCAPES.

A reservoir at Gebel Aulia would be an insurance against one and a preventive of the other, if it were large enough, *i.e.* if it were capable of being raised to such a level as to form a flood escape, as well as a summer water storage reservoir. Such possibilities exist at Gebel Aulia by making the dam to hold a level of R.L. 380 as originally designed. It cannot yet be said whether this will be necessary but it should be allowed for in the design and the foundations made wide enough for eventual heightening to a flood protection level.

The alternative to a high dam at Gebel Aulia which would make it possible to use the high lying flat plains of the White Nile Province as a flood escape is to continue to use the Sudd Region for the purpose, by turning the torrents into the present swamp area in years of high flood on the Upper Nile. Eventually a choice may have to be made between the White Nile and the Upper Nile Provinces of the Sudan. The Upper Nile has good soil and an ample rainfall and is probably capable of great development, if relieved of the danger of flooding, while the White Nile has relatively poor soil and a poor rainfall. All round the swamps, especially on the west, there is a good population, while that of the White Nile is thin and has no means of increasing its production, being entirely dependent on rainfall, that is often inadequate.

Over-Year Storage.

It has been shown that the present supplies flowing in the Blue and White Nile can provide about 63 milliard cubic metres of water per annum for irrigation in Egypt and the Sudan in an average year, against a demand of 68 milliards if Egypt is fully developed. When the 63 milliards has been reached development must cease till further supplies are obtained from beyond L. Albert, from the Baro River or from the Bahr el Ghazal, and even the 63 milliards, the average demand, cannot be supplied without over-year storage at Lake Albert.

In a simple system consisting only of a reservoir and its out-flow the amount available for over-year storage in any year is the excess over the average in that year and the total that could be accumulated, if this were the case, is calculated in table XXVI below, in which it is assumed that a cycle similar to the years 1912–1926 recurs when the above stage of development is reached.

Table XXVI.—Quantity available for Storage in Lake Albert Reservoir if a 1912–1926 Cycle recurs, when total demands are 63 Milliards per annum.

Mean discharge of Lake Albert : 24·5 milliards M^3 p.a.

Year.	Discharge* of Lake Albert Milliards.	Excess or deficit From Mean. Milliards.	Cumulative totals. Milliards.
1912	18·0	— 6·5	— 6·5
1913	19·6	— 4·9	—11·4
1914	20·2	— 4·3	—15·7
1915	23·3	— 1·2	—16·2
1916	26·8	+ 1·3	—15·5.
1917	46·0	+21·5	+ 5·8
1918	46·7	+22·2	+28·0
1919	28·1	+ 3·6	+31·6
1920	22·4	— 2·1	+29·5
1921	15·5	— 9·0	+20·5
1922	12·9	—11·6	+ 8·9
1923	16·4	— 8·1	+ 0·8
1924	22·1	— 2·4	— 1·4
1925	18·9	— 5·6	— 7·0
1926	22·3	— 2·2	— 9·2

The maximum amount accumulated in the reservoir would have been about 32 milliards at the end of 1919, but even with the two very big years of 1917 and 1918 to provide a large excess for storage, there would have been a deficiency in eight years out of 15, even for the partial development that has been shown possible on the average.

* Taken from "Lake Plateau Basin of the Nile" and from gauge discharge curve given therein.

Capacity of Lake Albert Reservoir.

The capacity of the Reservoir must be greater than 32 milliards, for this is the amount of the over-year storage and on the top of that has to come the storage of the year. In an average year this storage period lasts for four months, June to September, during which the Lake discharge would be about 7 to 8 milliards. All of this could not be retained, for one milliard per month would have to be released for navigation water, bringing the amount retained during the year down to 4 milliards and the total required capacity, therefore, up to 36 milliards. But water will be so valuable that no chance of saving any should be missed and if instead of an average year occurring when the reservoir is holding 32 milliards as over-year storage, another big year were to occur a bigger capacity than 4 milliards additional would be required. A further important consideration is the fact that the reservoir is not at the head of a simple river system, but of a very complicated one, the discharge of whose branches does not vary in the same way as that of the Bahr el Gebel, so that it may happen that in years when this river is below the average, other rivers of the system are above it, and therefore some of the Bahr el Gebel water can be stored. The converse case may of course also happen, but this does not alter the view that an ample margin should be allowed in designing the dam. How much to allow as a factor of safety is a question of judgment, but the difference of a metre or two on the height of the dam will be no great matter and it is better to make it too large than too small. Moreover, eventually other supplies will be obtained from somewhere and, wherever they come from, increased storage capacity will then be required at Lake Albert, as will be shown by the following considerations.

If the extra supplies come from above Lake Albert, they must be stored there till required, obviously, but they may come either from the Bahr el Ghazal or the Baro. There will be no storage below these rivers, which is not already full, with the exception of the Gebelein site on the White Nile, just above the Gebel Aulia reservoir, where it is believed that about one milliard might be stored. Consequently any extra supplies coming from these two systems would pass straight on to Egypt and would cause a decrease in the demand from Lake Albert while they were flowing and a consequent increase in the required storage capacity at Lake Albert. Table XXVI shows there might have been a cumulative deficiency of about 17 milliards by the end of 1915 and that although this was wiped out and a reserve of 32 milliards accumulated in four years, yet to provide against a cycle like 1912–1926 it would be desirable to have an accumulation of 32+17=49 milliards. It is to be argued therefore that the desirable capacity of Lake Albert Reservoir is about 50 milliards and when the dam is built it should be designed on foundations to sustain a dam high enough for this purpose, though it may not be built to the full height at once. All expropriations of Lake shores and moving of ports due to turning the Lake into a reservoir should also be carried out on the basis of an eventual 50 milliards capacity, at least.

The area of Lake Albert is about 5,300 square kilometres and as its sides are for the most part very steep, so that a rise in levels causes no great increase in surface area, as a first approximation one may say that the storage capacity is about 5 milliards per metre change of level, and hence to obtain 50 milliards a range of about 9 to 10 metres is required. What should be the lower limit of this range is still to be determined, for it may be possible to obtain the required command by making the cills of the dam sluices below present low water level and thus diminish the height to which the water would have to rise above present high water levels. To come to a decision on this point surveys of the Lake shores and Albert Nile outlet are required, the former also being necessary to determine the capacity of the reservoir at all levels. The occurrence of flat swamps at the Semliki mouth at the south end of the Lake has already been mentioned, and Dr. Hurst has calculated that if they are flooded the surface area of the Lake may be increased by about 15 per cent.

Sites for Lake Albert Dam.

Pakwatch at about 15 kilometres from the Lake on the Albert Nile was suggested by Sir William Garstin as a suitable site for a dam and his opinion has been supported by other engineers. A contoured plan of the site, with borings, is required to enable a decision to be reached on the matter. It has also been suggested that a good site for a dam could be found near Nimule on the Albert Nile, the Uganda-Sudan frontier, 216 kilo-

metres from the Lake. There are numerous rock out-crops here and it stands just above the Fola rapids so that good foundations could almost certainly be found. A survey and borings of this site are therefore also required.

If the dam is built at Nimule, the problem of obtaining the required 10 metres command of the Lake level by lowering it below present low levels is rendered more difficult, for the bed of the river from the Lake to here is believed to be very high, so that heavy excavation on this reach might be required. On the other hand, the storage capacity of the reservoir would be increased by the volume of the valley so that the range required for a 50 milliards capacity would be decreased. Moreover the reach from Lake Albert to Nimule will have to be remodelled in any case, for it will be shown below that the required discharge of the Sudd Channel may be of the order of 2,000 cubic metres per second which is far more than the present channel can carry. A survey with contours and cross sections of the valley and river from the Lake to Nimule is obviously required.

An advantage of the Nimule site is that a dam there would control part at least of the torrential supply reaching Mongalla, for though the three biggest tributaries (Assua, Kit and Kaia) join the river below the Fola Rapids at Nimule yet probably about one third of the torrential supply comes from above this point.

A very important point to be considered in the design of the Reservoir is the question of evaporation losses, which are of more importance here than in most reservoirs, as it will be used largely for over-year storage, so that the wasting effect of evaporation continues for long periods. The great advantage of Lake Albert is that its sides are mostly steep; so that the increase in area and evaporation losses caused by change of level are negligible and will not diminish the discharge. To what extent this condition would be changed first by flooding the Semliki mouth swamps and secondly by putting the dam at Nimule instead of Pakwatch must be determined with considerable care. The first may increase the evaporation area by about 15 per cent and the second by about 15 to 20 per cent, or a total of 33 per cent for the two. Rainfall statistics for the Lake are scanty and evaporation data entirely lacking, but the former is shown by one station at Butiaba to be about 84 c.m. per annum while Dr. Hurst believes 1·50 metres per annum to be a fair figure for the latter.

This means that there is a nett loss of over 2½ milliards of water per annum due to evaporation, so that if the Lake area is increased by 33 per cent there will be an additional loss of nearly one milliard cubic metres per annum. This does not sound much compared with the mean Lake discharge of about 24 milliards but it has to come from somewhere and each extra milliard required becomes increasingly difficult to find. These considerations point to a reservoir with a range extending well below the present low water level, controlled by a dam at Pakwatch.

Salinity of Lake Albert.

The waters of Lake Albert are somewhat more salty than those of the other Lakes, but basing himself on such tests of salinity as have been made, Dr. Hurst has shown in a very ingenious manner that the use of the Lake as a reservoir will eventually decrease the salinity of the outflow. Further observations of salinity are required to enable this deduction to be confirmed and should comprise the analysis of samples at various seasons of the year from the Victoria Nile, Semliki River and Albert Nile, as well as from different places and depths on the Lake itself.

Use of Lake Albert Reservoir without a Sudd Channel.

It has been suggested that the Lake Albert Reservoir alone might be made to function so as to increase Egypt's water supply before the Sudd Channel is built, the proposal being to retain the flood waters of the Autumn in Lake Albert and release them in the winter to reach Egypt in the summer.

At the present stage of development, there is nearly always water to spare in Egypt in winter and it would be a good exchange to sacrifice 100 or 200 cubic metres per second at that period to gain the same or even a lesser amount in the summer.

If the proposal were to be carried out, the regime of the Sudd Region would be changed fundamentally, by maintaining high levels and large swamp areas during the hot period of heavy evaporation and little rainfall, and low levels and small swamp areas during the

cool period of heavy rains and low evaporation with the consequent loss of a great proportion of the rainfall on the swamps, for the run-off from this flat country must be very low, when it is dry. Further, at present the peak of the swamp discharge occurs when the Sobat levels are high but falling, while the proposed regime would produce maximum discharge when they were low but rising.

The above facts may entirely change the time of travel from Mongalla to Malakal as at present determined and there are so many unknown factors that it is not possible to say whether the proposal is feasible or not. The dam will have to be built anyhow and if it is completed before the Sudd Channel, it would be worth trying the experiment. To enable a forecast to be made of the probable effect the data required are a knowledge of the evaporation in the Sudd, the area of the Sudd within a moderate range of levels, and the volume of the White Nile Valley above the Sobat mouth. Of the above, the evaporation statistics are already being collected and the contoured plan of the White Nile Valley has been made, but the area and levels of the swamps are not known. To take cross sections through them presents practically insuperable difficulties, but a levelled traverse round the edges, with cross sections run down to the low level limit of the swamps might be made. This information would also be required in connection with calculations for the use of the Northern or Lake No swamps as a flood escape, (Chapter V), and the Pharaonic Project described in Chapter VI.

Summary of Data Required.

The surveys and other data required to prepare a project for turning Lake Albert into a reservoir are therefore as follows :—

(A) Hydrological.

(1) Discharge of the Albert Nile at the Lake.

(2) Discharge of the Albert Nile at Nimule. (This is already being taken).

(3) Discharge of the Victoria Nile at Lake Albert.

(4) Discharge of the Semliki River at Lake Albert.

(B) Physical.

(1) Rainfall on the Lake—more stations required.

(2) Evaporation on the Lake.

(3) Salinity of the Lake.

(4) Salinity of the Lake tributaries.

(5) Salinity of the Lake discharge (Albert Nile).

(C) Geographical.

(1) Survey of the Lake shores, including contours to levels of some metres below present L.W.L. as well as 10 to 15 metres above that level.

(2) Survey of Valley and river bed with contours from the Lake to Nimule.

(3) Survey of dam site near Pakwatch with borings.

(4) Survey of dam site near Nimule with borings.

(5) Survey round boundary of Sudd Region with contours.

CHAPTER V.

THE SUDD CHANNEL AND REMODELLING OF THE UPPER NILE.

By the term Sudd Channel is meant the actual Channel that shall lead the waters of the Lake Plateau basin of the Nile through or round the Swamps of the Southern Sudan, but as these waters will be stored in Lake Albert and have to reach the Main Nile, a study of the whole river from the Lake to Khartoum is necessary, a length of over 2,000 kilometres.

Above and below the Swamps, the water will have to flow in the existing channel which will however be found to require remodelling. For the middle section several alternative routes seem possible, some of them in entirely new channels, some in entirely old ones, and some in a combination of new channels with remodelling of old ones.

Final size of the Channel.

A preliminary to any investigation or discussion of possible routes must be the determination of the final size of the channel required. The exact discharge cannot yet be fixed but at least it must be ascertained whether it will be of the order of 1,000 cubic metres per second or double that quantity. It would be of the greatest utility, too, to fix some approximate period in which the final size is to be reached, for the question of time is of importance in deciding whether to make a subsidiary or false work that will on forther expansion become useless, or, whether it is better to sink the capital in the main work, even though it could not be used to the full for some years. As however the period of completion cannot well be less than 50 or 60 years and may be more, the financial and political conditions which govern its progress as much as the purely engineering conditions are liable to such changes that it would be hazardous to fix any date.

The approximate size of the Sudd Channel can be deduced from a consideration of the discharge Egypt requires in the test year 1925-26 at a time when the whole, or practically the whole, supply must come from the White Nile. This period is April, May and June and specifically April, as during this month (Aswân dates) the whole of the Blue Nile discharge will probably be taken by the Sudan and the Sobat discharge is of negligible amount, about 60 cubic metres per second at Aswân. Gebel Aulia Reservoir will have been emptied to meet the deficiency in February and March, so that in the most favourable conditions, at the beginning of April, the Higher Aswân will still be full, holding say 5 milliards of water partly retained from the flood and partly sent through the Sudd Channel in January. This 5 milliards plus the Sudd Channel contribution has to meet the require ments in April, May and June and if 2 milliards were used in April the quantity to come down the Sudd Channel in that month would be about 2·4 milliards or about 1,000 cubic metres per second at Aswân. The most unfavourable conditions would probably not be worse than to allow at least one milliard to be taken out of Aswân Dam in April, leaving 3·4 milliards, or 1,400 cubic metres per second at Aswân, to come from Lake Albert.

To obtain a given discharge at Aswân double the amount must be released from Lake Albert and hence the foregoing discussion indicates that the size of the Sudd Channel will be between 2,000 and 2,800 cubic metres per second at Lake Albert and between 1,400 and 2,000 cubic metres per second at Malakal. It will not be necessary to fix its final size till long after the various reservoirs are made and in operation, when actual experience will have shown how to manipulate them so as to reduce the maximum demand and it is not improbable that one of the chief functions of the Tana Reservoir in the future will be to equalise the demand on the Sudd Channel. It is clear however that we have to deal with a channel of about 2,000 cubic metres per second capacity in the Southern Sudan and not of 750 cubic metres per second as was thought in the early days of investigation. This fact changes the conditions of the problem in a very important manner, for when the maximum size was considered to be about 750 cubic metres per second it would be worth while, perhaps, to deviate from the shortest route for a new cut in order to pick up an existing channel of about 150 cubic metres per second capacity, equal to 20 per cent of what was finally required, but when the final size is known to be about 2,000 cubic metres per second capacity an existing channel of 150 cubic metres per second capacity has very much less relative value, and the extra excavation involved in deviating from the shortest route may well turn out to be greater than the saving due to using the existing small channel.

The Upper Nile carried a discharge of over 2,000 cubic metres per second in 1917; an observation of 2,700 cubic metres per second having been made at Mongalla in September of that year, while the maximum reached there was in the neighbourhood of 2,900 cubic metres per second probably. At this time the whole country was under water and the Southern Sudan south of the White Nile and west of the Sobat was one huge lake. The water took a long time to flow away and the maximum discharge of this flood at the northern end of the swamps did not occur till March 1918 when the discharge of the White Nile at Malakal reached nearly 2,000 cubic metres per second. Such conditions are not permissible as a normal state of things and the future discharge of the same order of magnitude must be strictly confined within banks, involving the canalization of the Nile from Lake Albert to Khartoum.

This canalization falls naturally into three main sections as follows :—

(1) From Lake Albert to the southern limit of the Swamps, say Bor, on the Bahr el Gebel.

(2) Through or round the Swamps from Bor to the White Nile at the Sobat mouth. This section is the Sudd Channel proper.

(3) From the White Nile below the Swamps at the Sobat mouth to Khartoum.

The boundaries between these three sections cannot be quite clearly defined without further study, for in the first place there is a possibility that it will be more economical to make a new channel in the section Rejaf (foot of the Rapids) to Bor on the Bahr el Gebel than to canalize the existing water way and secondly the various alternative routes for the Sudd Channel proper debouch between Lake No and the Sobat mouth on the White Nile and thus vary the length of canalization involved in section 3.

The "Supra-Swamp" Section.

In Section 1 from Lake Albert to the Swamps, the reach Lake Albert to Nimule will certainly require remodelling and to enable the necessary designs to be made the same geographical data (plan with contours and cross sections) are required as were shown to be needed for choosing whether the site of the Lake Albert Dam is to be at Pakwatch or Nimule.

Knowledge of the next reach, Nimule to Rejaf, is practically nil, but it is known to be a series of rapids with intervals of smooth river and to have a very steep fall while it is believed to be mostly well within deep banks. Whether however it can carry anything like 2,000 cubic metres per second without serious spilling still has to be discovered and a reconnaissance, at least, along the river banks is required to see whether an accurate survey is necessary or not. This reach is however almost certainly able to carry about 1,000 cubic metres per second without other than normal losses, therefore its investigation can be deferred and given a late place in the list of required information.

The last reach of the " Supra Swamp " section, Rejaf to Bor, is well known and carries a regular steamer service. Hydrologically it is known to be very wasteful as has been shown in Chapter II but geographically our knowledge of it is insufficient, for no accurate survey or cross sections of the river valley exist. These should have an early place on the list of information required for they are needed to design the remodelling of this reach which will be required whatever line is taken for the Sudd Channel proper. It is possible, but not very probable, as already stated that it may be found advantageous to begin the Sudd Channel at Rejaf, by making a new cut on the east bank, rather than to remodel the bed of the river. After sections have been run across the river valley it is a small matter then to prolong each for a few kilometres eastwards on the high land, to enable the question to be decided definitely. Provisionally this reach will be considered as forming part of the first section.

Alternative lines for the Sudd Channel.

The next section is the Sudd Channel proper and whatever route is finally chosen, it will take many decades to complete.

It is therefore not practical to neglect all intermediate stages and work out simply what would be the most economical project could it be carried out without interruption

and were no benefits required from it till completed, but it is on the contrary essential to design the project so that it shall give a definite result in a continuously increasing water supply for Egypt and shall involve a minimum of false work. Such considerations may very well decide the choice among the various alternatives and the study of the project must therefore be arranged accordingly.

The various lines suggested for the Sudd Channel from Bor to the White Nile are shown on the map and are as follows :—

(1) Make a new channel direct from about Rejaf to the mouth of the River Sobat on the White Nile.

(2) Make a new channel direct from about Bor to the mouth of the River Sobat on the White Nile.

(3) Make a new channel from about Bor to about kilometre 175 on the Bahr el Zeraf, remodel the Bahr el Zeraf thence to its mouth on the White Nile and remodel the White Nile from the mouth of the Bahr el Zeraf to the mouth of the River Sobat.

(4) Make a new channel from Bor to the mouth of the River Sobat, but instead of being in a straight line to bend in towards K. 175 on the Bahr el Zeraf, join this angle to Kilometre 175 by a cut equal in carrying capacity to that river, and use both the Bor-Sobat cut and the Zeraf, remodelling the White Nile only from the mouth of the River Sobat.

(5) Remodel the existing main channel of the Bahr el Gebel from Bor to Lake No and the White Nile channel thence to the mouth of the River Sobat.

(6) Remodel the Bahr el Gebel from Bor to the Zeraf Cuts, then follow the Bahr el Zeraf to its mouth on the White Nile and White Nile to the Sobat.

(7) Remodel the Bahr el Gebel from Bor to Lake No and also the Bahr el Zeraf from the Cuts to its mouth using both the channels on the last reach and remodel the White Nile from Lake No to River Sobat mouth.

(8) Make a new channel going eastwards from between Mongalla and Bor to pick up the line of the River Veveno, follow this channel to the River Pibor and along the River Pibor to the River Sobat and along the River Sobat to the White Nile.

(9) Make a new channel on the Veveno-Pibor line, as in Project 8, and use the existing channels of the Bahr el Gebel from Bor to Lake No and of the Bahr el Zeraf from the Cuts to its mouth to carry such discharge as is possible without remodelling but only closing off spills, and remodelling the White Nile, from the mouth of the River Sobat.

These projects can be divided into two main groups : Group I, projects 1, 2, 3, 4, 8 and 9 involving the cutting of entirely new channels for all or part of the route and group II, projects 5, 6, and 7, involving only the remodelling of existing channels.

Group I (with the exception of the Veveno-Pibor Projects) has the advantage that the lines are shorter than those of group II, and transmission losses will therefore be less when completed and probably the final cube will be less than for the more circuitous routes that use existing channels. Moreover the swamps are avoided with all their unknown difficulties in dredging, future maintenance of channels and banks, formation of banks on swampy sub-soil with consequently heavy seepage losses or alternatively the removal of thick layers of decaying vegetation to find a suitable foundation for banks. The chief disadvantage of the new cut group is the length of time between beginning excavation and the completion of the first cut, while the chief advantage claimed for Group II that uses existing channels is that smaller projects can be designed, which will give a quicker though small return in increased water supply for Egypt.

Utility of Sudd Channel without Lake Albert Dam.

Before discussing in detail the above proposed lines for the Sudd Channel it will be well to consider what would be its utility without the Lake Albert Dam, if any.

The whole Mongalla discharge might be led to Malakal without other than normal transmission losses and thus increase the Swamp discharge at Malakal nearly always. It has however occasionally happened that the Mongalla discharge in the spring for short

periods is very little greater than the Malakal swamp discharge at the same time, therefore the effect of the Sudd Channel, allowing for losses en route and lag, might be to decrease the supply reaching Egypt. This would have been the case in March 1923, for instance, and generally speaking in years of poor supply in the Upper Nile such as the series 1922–1926 the excess of the Mongalla discharge over the Malakal swamp discharge is so small that it does not seem worth while making a channel several hundred kilometres long to carry it. The following table XXVII gives total discharge in the months of March, April, May of the Bahr el Gebel at Mongalla and of the Swamps at Malakal for the above years and shows the addition to the latter that a Sudd Channel would have made, assuming 15 per cent losses from Mongalla to Malakal. The time of travel between the two places via the Sudd Channel will probably be 10 to 15 days, but is neglected in the table.

TABLE XXVII.—COMPARISON OF SPRING DISCHARGE OF THE BAHR EL GEBEL AT MONGALLA WITH SPRING DISCHARGE OF THE SWAMPS AT MALAKAL.

Totals for March, April, May in millions m³.

YEAR.	Mongalla.	Mongalla less 15% (A).	Malakal Swamps (B).	Possible increase in Swamps discharge (A–B).
1922	3,259	2,801	2,240	561
1923	3,198	2,716	2,190	526
1924	4,979	4,242	3,040	1,202
1925	4,554	3,871	2,805	1,066
1926	4,639	3,943	3,470	473

Thus during the three spring months in years like 1922, 1923 and 1926 the Sudd Channel could only add about half a milliard cubic metres to the Swamps discharge at Malakal equal to about 350 millions, or about 4 millions per day, at Aswân.

In addition to bringing down the spring supply, a Sudd Channel could also carry any required amount of the flood discharge at Mongalla and this might be useful for filling Gebel Aulia Reservoir, if it existed, in years of poor supply. Of course the swamps themselves would have to be maintained as a flood escape, for the whole Mongalla flood discharge is not required in Egypt, where it might prove a danger, and is too big to be stored at Gebel Aulia. Without either Lake Albert or Gebel Aulia Reservoir the channel would be of very limited value for in the very years when it was most needed the extra supply might be nil, or even negative, at the critical period.

There is however a chance that the channel could afford an addition to Egypt's supplies in a good many years in the spring, if it were used only for those months and the ordinary regime remained unaltered for the rest of the year. This will be described in the discussion on project 3 for the Sudd Channel.

The foregoing considerations apply to a complete channel, whatever its line, but for the lines that follow the existing channels the advantage is claimed that every section of the Channel completed, starting from the north, will improve Egypt's water supply. This is based on the fact that the Sudd losses are due to evaporation and hence if any part of the swamps is cut off from access to the water, the swamp area and evaporation losses will be by so much decreased. Thus if the first 100 kilometres of the Bahr el Gebel from Lake No southwards were embanked and remodelled and lateral banks made across the swamps from the head of the remodelling, the water flowing in the river at that point could be led to Egypt with only normal transmission losses, and saved from the losses that would have been incurred in the portion of swamp that has been cut off by the banks. To make any such project there must be information available of the relationship in time and magnitude between the discharge at various points in the swamps and the corresponding discharge at Mongalla or Bor and Malakal. This information does not exist and will take many years to obtain, as has been shown in Chapter II, and it is almost certain that owing to the present lag from Mongalla to Malakal, in many years in spring the discharge of the river in the Swamps is not appreciably greater and may even be less than that of the Swamps at Malakal. The cost of such a project, which might involve only quite light banks to the Bahr el Gebel, might however be comparatively small and worth while, even if it only added to Egypt's summer water supply in three or four years out of 5, therefore

the investigation necessary to decide on the point should be put in hand, more especially as the same data will be required to determine the stages of the Sudd Channel (if it follows one of the present river lines) in conjunction with the use of Lake Albert Reservoir.

The conclusion seems to be that the Sudd Channel without Lake Albert Reservoir would be of some use in all years, if there were a reservoir at Gebel Aulia, but least when it was most wanted. If a new cut line is chosen, the whole length must first be completed to a section of a carrying capacity greater than the present spring swamps discharge and even then in the years of bad supply, it will add nothing to Egypt's summer water. If an existing channel line is chosen for development any length constructed will add something to Egypt's water supply, except in bad years, as soon as its new carrying capacity is greater than its present one.

PROPOSED NEW CUTS.

Projects 1 and 2.

The Rejaf-Sobat cut is only a modification of Project 2 the original Bor-Sobat cut, first suggested by the late Mr. J.S. Beresford C.I.E., M. Inst. C.E. to Sir William Garstin, who after his visit to the Sudan in 1904 urged its construction in the strongest terms, saying that if levels show it to be impossible of construction " then and only then " (to use his own words) should other projects be considered.

At that time it was thought that the ultimate size of the Channel would not have to exceed a capacity of about 750 cubic metres per second and that the minimum volume flowing in the Bahr el Gebel would never be less than this. It is now known that Egypt's future requirements are far greater while the minimum flow at Bor is often for long periods very much less than 750 cubic metres per second, and that heavy losses occur in some conditions between Rejaf and Bor, so that the question of the Rejaf-Bor reach must be considered, as already described.

One of the first problems investigated years ago was this one of the Bor-Sobat cut. A line of levels was run and the project found to be quite easily possible (this has since been confirmed by precise levelling) but nevertheless the project was decided to be unsuitable in very early days and attention concentrated on the improvement of existing channels rather than the construction of a new one. The chief reason that caused the decision appears to have been a reluctance to abandon the fine water way of the Bahr el Gebel and the difficulty of maintaining communications along the Bor-Sobat line during construction. There was also the important consideration that work along the new line could produce no result till the first cut had been made on the whole length which, with the means of excavation then available might have taken many years whereas work on improving the existing channel could, it was thought, be so planned as to increase the discharge progressively. These reasons seem now in large measure to have lost their cogency, for the value of the existing channels has decreased relatively owing to the much larger size of cut now required, and secondly the means of excavation have improved vastly, the utility of land excavators having been proved under many varied conditions though no doubt dredgers are still the more economical machines.

A railway along the canal line would solve the transportation difficulty and is now a feasible proposition, for its cost is a much smaller proportion of the cost of the present proposed size of channel than it was of the cost of the original size. It would seem inadvisable to rule out this fine proposal, or some modification, without a comparison of careful estimates of time and cost with those of the other projects. The collection of the geographical data for this project is well advanced, for a great part of the southern half of the area through which the cut would have to go has already been contoured, and a line of precise levels run from the Sobat mouth to Bor, while the hydrologic data specific to this project as distinct from the general problem, have been observed for some years, though not yet long enough. The data in question are river discharges and levels at Bor, and levels in the White Nile on the reach Malakal to Lake No. The former have been observed since 1925 and the latter for many years at some points on the reach, and since 1925 at all necessary points, namely Lake No, Khor Yergol, Tonga, Zeraf mouth, Khor Lolle Tail, Bahr el Harami Head, Sobat mouth, Tewfiqia and Malakal.

The large number of levels being collected are needed not so much for the study of the main project, as for the important detail of how to maintain navigation with the Bahr el Ghazal province either along the White Nile or along a remodelled side channel, whatever project is eventually carried out.

There is no doubt however that a long period would elapse between beginning the project and the first return in the shape of extra water and the two following projects Nos. 3 and 4 have been suggested with a view to overcoming this difficulty and yet retaining as far as possible the advantages of the straight route and clean cut of the Bor-Sobat line.

PROPOSED NEW CUTS COMBINED WITH EXISTING CHANNELS.

Projects 3 and 4.

No. 3 Project, known as the New Zeraf project, was designed by Mr. W.D. Roberts and its preliminary stage sanctioned for construction by the Council of Ministers in 1925. A new cut is to be made from about Bor to about kilometer 175 on the Bahr el Zeraf keeping just east of the swamps, and from kilometer 175 to the mouth the Bahr el Zeraf itself was to be developed and remodelled, and eventually also the White Nile from the Zeraf mouth to the River Sobat mouth. Kilometer 175 is a crucial point on the Bahr el Zeraf as from about here to the mouth there are no swamps on this river to cause abnormal losses. The great advantage of this line is that dredgers could start work on it not only at each end but also at intermediate points, by making short cuts from the swamps to the line. Work might thus be going on at four or five points in all and hence the first cut could be completed in a comparatively short time. This line to the White Nile is of course appreciably longer than the direct Bor-Sobat line and therefore more costly though for the latter part of its course it would follow an existing channel of roughly 150 cubic metres per second capacity which saves excavation, and also it involves remodelling about 40 kilometres of the White Nile between the mouths of the Bahr el Zeraf and River Sobat. It would certainly in the end be more costly than the direct line, but if it produced considerable advantages at an early stage might none the less prove preferable.

The proposed hydraulic operation of this project is based on the fact that the time, of travel of water from Mongalla to Malakal through the Swamps is about three and half months and hence it is assumed that the effect of abstracting water from the Bahr el Gebel at Bor above the Swamps would not be felt at Malakal, below the Swamps, for that period.

When the cut is made, it will carry normally the present discharge of the Bahr el Zeraf, varying on the average from about 110 cubic metres per second to 170 cubic metres per second, though falling as low as 60 cubic metres per second (1922) and rising to 330 cubic metres per second (computed 1918). On about March 1st, each year, the head regulator gates will be opened more and the discharge increased by such an amount as the channel at that stage of its excavation can carry. It is hoped that this increase in discharge of the cut will prove to give an increase of the same amount (less normal transmission losses) to the discharge of the White Nile, which here consists of the Bahr el Gebel, Bahr el Ghazal, and Bahr el Zeraf, *i.e.* that abstracting the extra water from the Bahr el Gebel at Bor and pouring it down the Bahr el Zeraf will not have decreased the discharge of the Bahr el Gebel at Lake No. This process is to continue for about three months, when the opening of the head regulator will be decreased till it is taking only the normal flow of the Bahr el Zeraf and the normal regime of the Swamps will be restored. The assumption that this can be done year after year is based on the fact that the spring discharge of the swamps at Malakal depends only on the flood discharge at Mongalla in the previous autumn, independently of whether the swamp levels were low or high when the flood arrived. This appears to be true within a very wide range of natural conditions from those of 1923 to those of 1917, but what would be the exact effect of the proposed disturbance of the natural regime must remain somewhat doubtful for the following reasons. The maxima and minima of the Swamps discharge-date curve are the result of a number of natural phenomena, of which the Mongalla discharge is the most important. If this complex is interfered with by artificial means such as the action of the proposed New Zeraf Cut, the balance may be entirely upset and it is impossible to predict what the result will be. Further though the period of three and half months is the mean of the intervals between occurrence of maxima and minima respectively at Mongalla and Malakal, yet this period has varied from about one month to about six months. (Table XIII). It has been shown, too, how very uncertain the observations are from which the dates for the maxima and minima at Malakal are deduced, though, if there is no systematic error, the large number of years from which the mean is calculated will give a fair idea of the average interval, but the probable error will be large. Moreover what has been calculated is the time from Mongalla, not from Bor, to Malakal, and it has been shown that there is an undetermined but sometimes not inconsiderable lag from Mongalla to Bor.

The regime of the southern portion of the Swamps will be permanently altered by making the head of the Zeraf at Bor instead of at the Cuts. This is probably an advantage as it will decrease the volume and level in the Swamps, and therefore the area and evaporation losses, but it may entirely change the time of travel, on which the whole success of the project depends. There should however be some balance of benefit due to the reduction of the discharge entering the Swamps, but until the channel is big enough to carry a discharge larger than the total Swamps discharge at Malakal there will be no assurance of increasing Egypt's water supply by any sensible amount.

The New Zeraf is to be enlarged progressively till it carries a discharge about 250 cubic metres per second greater than the mean discharge of the present Zeraf, *i.e.* about 400 cubic metres per second at the head and 360 cubic metres per second at the tail. This figure was chosen as the White Nile in the Lake No–Malakal reach can carry about 250 cubic metres per second more than at present at summer levels and slopes, without remodelling and without undue losses. No barrage is to be built at Bor, below the head regulator of the New Zeraf, till this stage has been reached it being assumed that the discharge will enter the channel if the gates are opened wide enough. This is contrary to accepted irrigation practice and will probably give a lot of trouble in regulation.

While the cut is being enlarged to the 400 cubic metres per second size, the investigation of Lake Albert is to be completed and a dam built there, as well as a barrage at Bor. A barrage across the White Nile upstream of the Zeraf junction is also to be built to prevent the new water that will come down the Zeraf ponding up the White Nile. The necessity for this work is not clear if the White Nile is either now capable of carrying the extra discharge or is to be remodelled to make it so.

As soon as the Albert Dam and Bor Barrage are built the operation of the New Zeraf is perfectly straight forward, for water will be released from the Lake in sufficient quantity to keep the channel full and about 200 cubic metres per second flowing down the Bahr el Gebel. The problem of how to deal with the torrents has not been settled, nor the levels at which the New Zeraf, the Bahr el Gebel and the White Nile are to run. It seems clear however, that if the Lake Albert Dam and Bor Barrage are built at once, Egypt can be assured of extra water along this route as soon as the New Zeraf has a capacity of about 200 cubic metres per second, as about 200 cubic metres per second can also flow without abnormal losses down the Bahr el Gebel. It seems therefore that the above masonry works should be built as soon as possible and not relegated to the future.

To complete the study in the field of this scheme further hydrological data only are required regarding discharges and levels at Bor, in the White Nile and on the Bahr el Gebel between Bor and Lake No. The requisite data at Bor and in the White Nile are being observed, but on the Bahr el Gebel below Bor there are only discharge stations at the Zeraf Cuts and Lake No and it is doubtful whether these will give enough information to determine levels and discharges for the subsidiary use of the Bahr el Gebel. Observations should be begun as soon as possible at Kenisa and Buffalo Cape, and possibly Hellet Nuer, or a total of three or four intermediate stations between Bor and Lake No. These observations will also be required in connection with the study of some of the other projects, as will be shown below.

The preliminary survey for the line of the cut is finished and cross sections of the Bahr el Zeraf also exist, so that the main geographical data are available, though much detail still doubtless requires to be filled in.

The estimated cost of this project is L.E. 4,700,000 and the water that Egypt will receive in a normal year, if the scheme is successful, will be about 1½ milliards, or over L.E. 3,000,000 per milliard cubic metres of water. If it succeeds, Egypt will begin to get extra water after about L.E. 1,000,000 has been expended and the new cut has a capacity of about 110 cubic metres per second. If it does not succeed in producing extra water so quickly, the only harm done is that a line has been chosen for the Sudd Channel which is probably not the cheapest, though cheaper than some. To be certain of getting extra water at the earliest time possible, Lake Albert Dam and Bor Barrage should be begun without delay.

A variant of the above project is No. 4, now suggested for the first time, it is believed. This project proposes a new cut from Bor to the Sobat mouth, but instead of being in a

straight line it is to bend westwards, the apex of the angle it makes being near kilometer 175 on the Bahr el Zeraf. This angle is to be joined by a small channel to kilometer 175 Bahr el Zeraf.

Excavation of the new cut is to begin at Bor, the Sobat mouth, kilometer 175, and at as many intermediate points between Bor and kilometer 175 as possible. As soon as a first cut has been made from kilometer 175 to the angle of the new line, excavation is to begin from here towards Sobat mouth as well as towards Bor. By the time the line (kilometer 175—angle of Channel—Bor) is completed to a capacity of 110 cubic metres per second the first cut right through from " Angle of the channel " to Sobat mouth should also be completed, and after that any increase in the capacity of the south part of the channel from the Angle to Bor will produce an increase of water supply. Thus if the method of early operation of project 3 is successful, project 4 takes advantage of it but if it is a failure then project 4 has the advantage of following a shorter route than project 3, while making full use of the existing capacity of the Bahr el Zeraf through the junction, about 40 kilometres long, between the " Angle of the new cut " and kilometre 175.

The comparison of the lengths of channel to be excavated in the two projects is given below :—

Table XXVIII.—Comparison of Lengths of Similar Excavation in Projects 3 and 4.

Excavation.	Project 3, length in kilometres.	Project 4, length in kilometres.
Excavation for 2,000 m3/sec.	300	260
Excavation for 1,850 m3/sec.	100	110
Excavation for 150 m3/sec.	Nil.	40
Remodelling White Nile	40	Nil.

The above table shows that the advantage is heavily in favour of project 4, for the eventual remodelling of the White Nile for 40 kilometres is probably a far bigger work than making a channel to carry 150 cubic metres per second for the same distance. Project 4 may take somewhat longer before a first benefit is received if only dredgers are employed, but if speed is essential land excavators could work ahead of the dredgers, using the dredgers as a floating base. After the first cut is made subsequent additions could be obtained for less excavation on project 4 than in project 3, for the main line is shorter. The hydrologic data required for working out this project are the same as for projects 2 and 3 and the geographic data are a survey of the area through which the northern portion of the cut is to be dug, which is also required for the study of the direct Bor-Sobat cut.

Proposed Remodelling of Existing Channels.

Projects 5, 6 and 7.

The next three projects, Nos. 5, 6 and 7, all propose to use only existing channels of the Bahr el Gebel and Bahr el Zeraf either alone or in combination, and the consequent remodelling of the White Nile from Lake No or Bahr el Zeraf mouth. It seems probable that any of these lines will be more expensive than the shorter direct cuts, even though there is an existing channel, but this cannot be stated definitely till actual cubes have been worked out. Many cross-sections of the Bahr el Gebel exist but they need revision and reference to a known datum, for their sites are not known very closely and at the time they were taken there were no accurate levels known along the Bahr el Gebel. Gauges whose precise levels have been obtained now exist at Kenisa, Shambe, Zeraf Cuts, Hellet Nuer, Buffalo Cape and Lake No, while the levels of gauges at Ghabat Inderab and Awai

Tail are known to a lesser degree of accuracy. The revision of the Bahr el Gebel cross-sections can therefore now be taken in hand to give an accurate basis for calculating the amount of work required to remodel this river. For the Bahr el Zeraf this revision has already been nearly completed.

If this project is to be studied with a view to gradual development starting from the north, it is essential to know what discharges and levels are to be found at various points in its course corresponding to known discharges at Bor and for this purpose the same series of discharge stations is required as was shown to be desirable for studying the subsidiary use of this river in other projects.

The great length of the Bahr el Gebel and the necessity for remodelling the White Nile for 80 kilometres from Lake No to the Zeraf mouth, that its use would entail eventually, caused the project for its development to be abandoned in favour of the alternative line of the Bahr el Zeraf, though the possibility of using the lower reaches, undeveloped, as a subsidiary channel was kept in mind.

The Zeraf Cuts Project of 1910.

The project whose construction was begun in 1910 provided for a final swamp discharge of 750 cubic metres per second, which was to be carried by the Bahr el Zeraf from the Cuts northwards. The first step was to make the Cuts connecting the Bahr el Gebel and Bahr el Zeraf at about 300 kilometres from their mouth, and thus increase the Bahr el Zeraf discharge by about 150 cubic metres per second. It was hoped to effect this without diminishing the Bahr el Gebel discharge at the mouth. After the Zeraf discharge had been increased to this extent with slight works on the Zeraf Channel, the latter was to be enlarged till it carried 750 cubic metres per second and the Bahr el Gebel to be shut off at the Cuts. Allowance was made for various masonry works and the improvement of the White Nile Channel below the Bahr el Zeraf mouth.

The first stage of this project is based on the misconception that the swamps are a reservoir, though this had been shown conclusively by Mr. Dupuis to be unsound. After the first Cut was made, it was found that the Bahr el Gebel discharge a few kilometres downstream had not been decreased and this was thought to be due to the river regaining from the so-called reservoir the water that had been abstracted down the Cut. As a matter of fact the phenomenon was due to the existence of a side channel, now known as Peake's channel, but at that time undiscovered, perhaps cloaked with vegetation. This channel takes off the Bahr el Gebel well above the Cuts and above the site where the upstream discharges are taken and joins it again below the Cuts, above the downstream discharge site, so that the river appears to gain.

Moreover in those early days it was accepted as a dogma that the discharge of the Bahr el Gebel was constant. Compared with rivers like the Blue Nile and Atbara this may be considered true, but absolutely it is far from being the case as the flow is subject to variations quite as large as those which the project was to produce. This is clear even from a study of the data available at that time, for the minimum computed variation in a year had been from 290 cubic metres per second to 382 cubic metres per second in 1908, and the maximum in 1910 when it varied from 195 cubic metres per second to 493 cubic metres per second. Even considering the critical months March to June only, the flow had varied by nearly 100 cubic metres per second in the period 1906 to 1912. It should therefore have been clear that the flow during a year and from year to year *could* vary and that therefore increasing the Zeraf discharge *could* lower the Bahr el Gebel discharge.

After the first stage of increasing the Bahr el Zeraf discharge through the Cuts, it was proposed to close the Bahr el Gebel by an earth bank and divert all the water down the Zeraf, thus bringing its discharge up to 750 cubic metres per second. No provision was made for any remodelling or other work on the Bahr el Gebel above the Cuts, so it is not clear where the 750 cubic metres per second were to come from, for no such discharge had been, or has since been, observed or deduced in the Bahr el Gebel above the Cuts, nearer than Bor, over 300 kilometres away, the biggest observed in the Swamps being about 600 cubic metres per second at about 100 kilometres above the Cuts.

A second cut was made close to the first in 1913, and the project then abandoned, for it was impossible to show that the works had done any good. To decide definitely whether they had done so it would be necessary to have a full knowledge of the swamp discharge relative to the discharge entering the swamps, both before and after the Cuts were made. The available data in this respect are very inaccurate as has been shown in the discussion on the time of lag in the Swamps and the conclusions to be drawn from it are therefore very doubtful.

The following Table XXIX compares the spring Swamps discharges with the Mongalla flood discharges before and after the Cuts were made and gives the percentage of the one to the other for each year. Series of years cannot be compared unless their discharges are the same or practically the same, for the percentage of water lost increases with the size of flood. Comparing the years before and after the Cuts were made that had similar discharges namely the pairs (1908-1919) (1908-1926) (1909–1914) (1909–1915) (1912–1920) and (1910-1918) it is found that five of these pairs show that a smaller percentage of the Mongalla discharge left the Swamps after the Cuts than used to get through before the Cuts, *i.e.* that the Cuts did harm, and only one pair (1910-1918) shows that the Cuts did good.

TABLE XXIX.—SHOWING PERCENTAGE OF MONGALLA FLOOD DISCHARGES THAT REACHED MALAKAL IN FOLLOWING SPRINGS BEFORE AND AFTER ZERAF CUTS WERE MADE.

Years.	Mongalla discharge September, October and November. mean m^3 sec. (A)	Malakal Swamp discharge March, April and May. mean m^3 sec. (B)	Percentage of A to B.	Remarks.
1905–1906	1,292	399	31	Before either Cut was made.
1906–1907	1,458	456	31	
1907–1908	1,211	417	34	
1908–1909	1,044	453	43	
1909–1910	1,167	478	41	
1910–1911	1,265	466	37	After No. 1 Cut was made.
1911–1912	961	394	41	
1912–1913	923	428	46	
1913–1914	714	410	57	After both Cuts were made.
1914–1915	1,084	433	40	
1915–1916	1,092	429	39	
1916–1917	1,793	578	32	
1917–1918	2,424	629	26	
1918–1919	1,327	523	39	
1919–1920	1,035	414	40	
1920–1921	864	372	43	
1921–1922	574	282	49	
1922–1923	631	276	44	
1923–1924	801	374	47	
1924–1925	746	383	51	
1925–1926	621	355	57	
1926–1927	1,038	437	42	

Arguments of many kinds have been used to show that the Cuts did or did not do some good, but they all come to grief owing to the insufficiency of data, an insufficiency that can never be remedied. There seems to be a slight balance against their having done any good, not only from the figures of table XXIX, but also from a consideration of the natural features. The original sources of the Bahr el Zeraf before the Cuts were made were through the Atem and Awai heads, as already described, and there was a feeder called the Khor Madmid, between the present Cuts. This was cleared of vegetation when the Cuts were made but has for long been overgrown again and carries practically no discharge. Before the Cuts were made the level of the Bahr el Zeraf in that neighbourhood was about one metre below that of the Bahr el Gebel and the making of the Cuts raised this level appreciably and therefore also the level and area of the swamps on the Zeraf, for that river is here not yet within banks. The levels on the Bahr el Gebel above the Cuts and therefore the swamp levels and area must also, it appears, have been increased by making the Cuts, for the water that previously left this river in this reach to feed the Bahr el-Zeraf no longer did so. An increase in swamp area means an increase in losses, so while the discharge of

the Bahr el Zeraf was not appreciably changed by making the Cuts, the losses in the swamps above the Cuts may have been increased. There is anecdotal evidence in support of the idea that the swamp area on the Zeraf near the Cuts has been increased, but no survey with levels. The question must for ever remain in doubt with the balance of probability against the Cuts having had any good effect.

THE VEVENO—PIBOR PROPOSALS.

Projects 8 and 9.

The last two projects for the Sudd Channel are those for using the Veveno—Pibor line, which was first suggested by Mr. O.L. Prowde C.M.G., M. Inst C.E., after the very high flood of 1917–1918, when the Mongalla water was supposed to have found an exit by this route. The Veveno in its upper reaches is little more than a shallow depression, but becomes better defined on approaching the River Pibor. Eventually, if this project were developed, no doubt the shortest line from the Bahr el Gebel to the Pibor would be used, and no attempt made to pick up the insignificant Veveno depression. The River Pibor is not much better, as can be seen from the typical cross sections attached, but the River Sobat has a fine channel, which is practically empty at the time the Sudd Channel should be giving its maximum discharge and conversely, when it is full, the Sudd Channel will have to carry only navigation and torrential water.

Therefore, on the face of it, the scheme seems to have many advantages, but the difficulty of dealing with the present flow of the tributaries of the River Sobat, however small, has to be faced. If the Sudd Channel levels are to be low enough to take the Sobat tributaries' supply at present levels, the excavation required will be very heavy, on the other hand if the Sudd Channel waters are to flow in the present Sobat bed, the levels of the tributaries will have to be raised considerably and the water therefore dissipated over the swamps between the Baro and the Pibor Rivers and lost. The chief tributaries of the River Pibor are the rivers Awei, Akobo and Gila, and our knowledge of their hydrology is practically nil, nor is much more known about the River Baro which joins with the River Pibor to form the River Sobat. Hence for a full study of this project the observation of discharges and levels of this system should be begun at once, as it must be several years before reliable means are established.

The geographical data required are a contoured survey of the country between the Bahr el Gebel and the Pibor, in the neighbourhood of the proposed line, and cross sections of the Veveno, Pibor and Sobat Rivers. There is believed to be a sort of water shed between the Bahr el Gebel and the River Pibor, with outcrops of ironstone rocks, which may indicate the existence of a rocky ridge forming a barrier so expensive to cut through as to make the scheme impracticable. It would therefore seem advisable in the first place to run a line of levels more or less due West and East to locate this ridge if it exists and to accompany this with borings extending down to the probable bed level of the channel.

Project 9 is practically the same as project 8, but would make whatever use possible of the existing lines of the Bahr el Gebel and Bahr el Zeraf. This does not necessitate the collection of any data that are not also required for other projects.

LEVELLING

The whole mass of surveys and hydrologic information required must all be based on one system of levels, whose main lines are practically completed. Lines of Precise levels have been run from Khartoum up the White Nile (both banks) to Malakal and from Malakal across country to Bor and to Rejaf, Nimule and Fajao on the Victoria Nile. The section Fajao to Butiaba has not been done, but would be of value as connecting Lake levels definitely with Bahr el Gebel levels.

From these main lines of precise levels spur lines have been run to gauges along the Bahr el Gebel, mostly also of the first order of accuracy, and little more is required on this river as precise bench marks exist with sufficient frequency to enable any required levelling to be done with little trouble.

A line of precise levels has been run along the River Sobat from the mouth to Nasser about 300 kilometres away, connected with the main system, and this needs extension along the Rivers Baro and Pibor and across country to join the Bahr el Gebel system(*) and form a base for contouring this area. A line has also been run from Lake No for about 100

(*) This was done in the winter 1928–1929.

kilometres along the Bahr el Ghazal to Arediba and will serve as a base for the study of the lower reaches of this river.

There are a number of problems in connection with the Sudd Channel that are common to all or most of the lines suggested. The first of these is the question of the headworks with which is bound up that of escapes and the level at which the Sudd Channel is to flow.

Headworks of the Sudd Channel.

The best site for the headworks, consisting of a barrage on the Bahr el Gebel, head sluice of the Channel and escape, will probably be near Bor, whether a new cut is made or the existing rivers remodelled, for it is only here that a suitable site for escaping excess waters is readily available, namely the Swamps. When the Channel is finished it will probably be large enough to carry any spates that occur and the question will then arise as to whether they are to be escaped into the Swamps, or carried down the Channel and either checked at Gebel Aulia or allowed to pass on to Egypt. In the early stages however the Channel will not be large enough to carry them and they must therefore do as they do at present—flood the Swamps.

All suitable sites in the neighbourhood of Bor therefore need to be mapped, the surveys and levels being carried well into the high ground on both banks to enable tie banks to be sited, for as this barrage may be required before the Rejaf—Bor reach is remodelled, such banks will be necessary to prevent out-flanking of the works.

Supply Level in the Sudd Channel.

Whether the full supply level in the channel is to be above ground level or below is a question that must be settled at an early stage. The fall from Bor to the White Nile is such as to make it possible to run above ground level and thus save heavily in excavation. There would of course be a certain danger from breaching of banks by elephants and hippotami, but the spoil of the excavation would be so large as to make the banks into veritable dams. There is also a danger of seepage causing permanent swamps along either side of the channel, but as the country is quite savage and mostly swampy now, this is perhaps negligible. The extra cost of digging the channel so deep that full supply level would be below the ground, as compared with a channel running at say 1 to 1·5 metres above ground level, should be worked out and weighed against the advantages to be obtained, among which will be greater ease in dealing with water running in the Bahr el Gebel if this is retained as a subsidiary channel. Escapes will probably have to be provided along the channel for ease in regulation, but the water thus escaped must be saved if possible. This could be done by running it into the Bahr el Gebel through existing Khors, improved, or through new cuts and then dealing with it as the Bahr el Gebel and Bahr el Ghazal water will be dealt with. To make such escapage possible, it would probably be preferable for water levels in the channel to be above ground level.

Danger from Vegetation.

The danger to channels built in the Sudd Region from vegetation has already been mentioned. It is a danger which is common to all of the nine alternatives, for the variation in water level in the channel during each year will depend not on the line of the channel, but on the fact that in some months the channel must run nearly empty carrying only navigation and torrential water, and those months are the ones when rainfall and other conditions appear to be the most favourable for plant growth. This is probably certain to appear on the sides and berms, and if care is not taken, on the bed too. It appears inevitable that the channel should be designed using the coefficients for weedy, and not those for clean, channels. Our ignorance of the ecology of the Sudd vegetation is complete and its study, which must take several years, is a matter of urgency, therefore one of the first steps to be taken should be the appointment of a botanist for the purpose*.

* This has now been done, 1929.

SILT.

The question of silt is closely allied to that of vegetation and may become of importance, for the water of the Bahr el Gebel, above the Swamps, carries silt though not in such quantities as the Blue Nile. The channel must be so designed as to carry this silt on and the question will then arise as to what extent it will be deposited in the White Nile and cause danger of silting the Gebel Aulia reservoir. A similar problem will occur with regard to the River Baro, whose waters are also fairly silty at Gambeila. Any project for confining this river by banks and preventing its waters spreading over the Baro-Pibor marshes will have the effect of causing this silt to be carried into the Sobat and White Nile and perhaps on to Gebel Aulia. A preliminary to any consideration of the problems raised is a knowledge of the silt content of the two rivers and therefore its determination at all seasons at Mongalla and Gambeila should form part of the researches still required.

BAHR EL GHAZAL FLOW.

The final point common to all projects is that of dealing with the Bahr el Ghazal flow and the drainage of the Swamps, for even after the Mongalla water has been prevented from entering the swamps there will be rainfall, subsoil drainage and very likely water from the Bahr el Ghazal swamps. The question of how to dispose of this is bound up with that of the levels of the White Nile after remodelling. Either the White Nile could be remodelled to run at such a low level that the Bahr el Ghazal and Bahr el Gebel would flow into it naturally or with only very slight ponding up, or a side channel could be cut parallel to the White Nile, using the Khor Lolle and Bahr el Harami, to carry the above water from near Lake No at a less slope than the White Nile till they had gained sufficiently in level to flow into the White Nile, or else they could be pumped into the White Nile. Probably a combination of some remodelling and lowering of levels in the White Nile, with some ponding up in the reach above the junction of the channel and this river and some extension of the above side channels will solve the problem, especially if the Bahr el Gebel is to be maintained as a subsidiary carrying channel for about 200 cubic metres per second.

Any ponding up in the White Nile would probably involve flooding the swamps round Lake No which are very flat and low lying and thus cause evaporation losses, but would have the advantage of forming a flood escape of fair size into which torrents might be escaped after passing down the channel, through a suitable opening near the tail. Another advantage would be the facilitation of navigation along the White Nile and Bahr el Ghazal which must be maintained.

To ensure that the Lake No pond should be formed only of Bahr el Ghazal and Bahr el Gebel waters, and that no Sudd Channel water should be lost a dam or barrage across the White Nile might be required above the junction with the Sudd Channel, and this dam would have to have a lock unless the alternative scheme of developing the Khor Lolle were adopted.

To choose between the above methods the various alternatives must be worked out and costs and advantages compared. The data required for this purpose are chiefly geographical, namely a contoured plan of the White Nile valley, which exists, cross sections of the Khor Lolle and its exploration to its head, and cross sections of the Bahr el Harami, and if possible some information about levels on the boundary of the Lake No swamps. The hydrologic data are chiefly discharges and levels in the White Nile and discharges of the Bahr el Ghazal, all of which are being observed.

GRAZING GROUNDS.

A point mentioned in Chapter I which is common to the first group of projects, those that include new cuts, is the question of the effect that such a cut will have on the grazing lands east of the river from Bor to about the latitude of the Cuts. These lands are watered either by the rise of swamp levels in flood or by rain water coming in Khors from the Abyssinian hills or by both, and it is obvious that the new channel may interfere with this regime and spoil the grazing. The location and levels of these areas will be or have been

determined in the course of the surveys for the various new lines which will also show the Khors coming from the east. To settle the point of the effect of the Bahr el Gebel flood it is necessary to know the water levels in the Swamps in relation to river levels. Gauges are therefore required at two or three suitable points in this neighbourhood which must be regularly recorded. They already exist at two suitable points, Jonglei on the River Atem and Khor Gurr on the Bahr el Zeraf, near either end of the grazing areas, and a third should be erected at some intermediate point.

Permeability of Soil.

A further problem that will arise only in those projects using existing channels is the permeability of the soil from which banks will be made or on which they will rest. The top layer of semi-solid material on either side of the Bahr el Gebel is a mixture of decayed and partially decayed vegetable matter and very fine silt, probably unsuitable either as foundation or material for banks. There will probably be enough spoil from the excavation to make banks without incorporating any of the above described mixture, but the question will arise as to whether it is safe to put a bank of good soil on such a foundation. It may be necessary to remove it, which would entail heavy additional excavation, and to ascertain its amount a survey comprising bores or samplings of the undesirable surface layer is required showing its thickness. Concomitantly it would seem desirable to carry out a few experiments to measure the permeability etc. of the material.

The "Infra-Swamp" Section.

Remodelling of the White Nile.

The third or "Infra-swamp" section of the remodelling of the Upper Nile consists of the remodelling of the White Nile from the Sobat mouth northwards. This river has carried a discharge of nearly 2,000 cubic metres per second in 1918 but only by flooding the whole country. Its mean maximum discharge is of the order of 1,200 cubic metres per second to 1,300 cubic metres per second, and at such levels the water surface is very wide and many swampy islands and berms cause losses, though their extent is not known. Discharges are only observed at Malakal and at the junction with the Blue Nile, over 800 kilometres away, and the two cannot be compared at high levels to calculate losses, owing to the complication introduced by the ponding up caused for several hundred kilometres by the rise of the Blue Nile flood. It would be advisable to begin discharge observations at at least one site(*) between Malakal and Khartoum above the ponding up and preferably at two, one near Kosti and one between Renk and Melut, so as to divide the river into three reaches. Before the result of such observations is known it is not possible to say whether the losses are so serious as to justify expensive measures before the last stage of the project is reached, when the Sudd Channel discharge approaches 1,800 cubic metres per second at Malakal. The prevention of such losses would probably only necessitate comparatively light banking, for whose design cross sections of the river are required and preferably a contoured plan of each bank.

Partial use of Bahr el Gebel.

But the remodelling must also be considered from another point of view, that of making it simpler to deal with the Bahr el Gebel and Bahr el Ghazal water, for it may be advantageous to run the White Nile at a somewhat lower level than at present, so that these two rivers can join it with less waste.

At what levels can the Bahr el Gebel, untouched, carry 200 cubic metres per second 250 cubic metres per second, etc., is the first question to be answered, and what remodelling of the White Nile is necessary to enable this Bahr el Gebel discharge to join it without ponding up and waste ? It is not merely a question of cost, but of the water, for it has

(*) Regular discharge observations were begun at Renk in 1928.

been shown that this cannot be spared, and as the water saved from wasting in the Sudd will cost somewhere over L.E. 5,000,000 per annual milliard (as against about L.E. 2,000,000 per annual milliard at Gebel Aulia or Aswân) a heavy expenditure is justified per annual milliard saved.

To make the necessary calculations to decide on the above points, no other data are required than those needed for decision on other points of the problem.

The discussion is now completed and a summary is given below of the data that have been shown to be needed to enable the remodelling of the Upper Nile to be designed, including the choice of the best line for the Sudd Channel proper. These are additional to the list of data at the end of Chapter IV.

Data Required.

HYDROLOGICAL.

Regular observations of discharges and gauges of :—

(1) Bahr el Gebel at Bor.

(2) Bahr el Gebel at Kenisa.

(3) Bahr el Gebel at Hellet Nuer.

(4) Bahr el Gebel at Buffalo Cape.

(5) River Baro at mouth. ‡

(6) River Pibor at mouth. ‡

(7) Rivers Awei, Akobo and Gila at their mouths, say fortnightly.

(8) White Nile at one or two places between Malakal and Kosti.

These are additional to the discharges already being taken namely :—

(1) Bahr el Gebel at Nimule.

(2) Bahr el Gebel at Zeraf Cuts, with discharges of the Cuts and Bahr el Zeraf.

(3) Bahr el Gebel at mouth.

(4) Bahr el Ghazal at mouth.

(5) White Nile below confluence of Bahr el Gebel and Bahr el Ghazal.

(6) White Nile above confluence of Bahr el Zeraf.

(7) River Sobat at mouth.

(8) River Baro at Gambeila.*

(9) White Nile at Malakal.

Regular observations of gauges at all present sites on the Bahr el Gebel and White Nile, with addition of gauges at.

(1) Jonglei on the River Atem.

(2) Khor Gurr on the Bahr el Zeraf.

(3) Gauge in the swamps between (1) and (2).

PHYSICAL.

(1) Continuation of present evaporation observations and, possibly, erection of one more large tank in the Sudd near Lake No.

(2) Study of the botany of the swamp vegetation.

(3) Determination of silt contents of Bahr el Gebel at Mongalla and River Baro at Gambeila at all seasons of the year.

(4) Experiments on seepage through banks made of, or erected on, the material forming the surface layer in the Swamps.

(*) Begun in Autumn 1928.

(‡) Begun in May 1929.

GEOGRAPHICAL.

All surveys to comprise soil survey by bores and trial pits, to give some idea of the nature of the material to be dredged.

(1) Line of precise levels from Nasser to Gambeila.

(2) Line of precise levels along the River Pibor to Pibor Post and thence along the River Veveno and across to the Bahr el Gebel(*).

(3) Surveys with contours and cross sections of the Bahr el Gebel valley from Rejaf to Bor, including a strip of the high land on the east of the river.

(4) Ditto of the area between the Bahr el Zeraf and the River Sobat.

(5) Ditto of the area through which the Veveno Cut might go, from the Bahr el Gebel (Mongalla-Bor reach) to the Pibor, with cross sections of the Veveno, Pibor and Sobat Rivers.

(6) Reconnaissance of the reach Nimule to Rejaf, with a few typical cross sections.

(7) Geological reconnaissance of line from Bahr el Gebel to the Pibor, with borings to determine presence or absence of rock.

(8) Completion of New Zeraf survey with details of Khors coming from the east.

(9) Detailed survey in neighbourhood of Bor to site the Barrage and tie banks.

(10) Cross-sections of the Bahr el Gebel from Bor to Lake No.

(11) Completion of cross sections of the Bahr el Zeraf.

(12) Detailed survey of suitable barrage sites on White Nile between Sobat mouth and Zeraf mouth.

(13) Survey of Khor Lolle from head, with cross sections.

(14) Survey of Bahr el Harami with cross sections.

(15) Cross sections of the White Nile from Malakal to Kosti. Below this point an accurate contour map of the river and banks exists.

(16) Survey of banks of Bahr el Gebel to ascertain thickness of detritus.

(*) This has been done. July 1929.

CHAPTER VI.

THE PHARAONIC PROJECT.

In view of the immense cost and long time required for the completion of the Sudd Channel project it may be worth while to investigate schemes for producing quickly an increase in the supply issuing from the swamps, even though the works necessary would not be of use for the Sudd Channel project proper, provided these are inexpensive. This word must be given a comparative meaning : " inexpensive " compared with the cost of other projects. An essential condition of such a scheme should be that the preliminary surveys and investigations should be of need for the other projects, so that the time and cost of making them would not have been wasted, should they show the small scheme to be not worth while.

This condition is fulfilled by the following project, put forward for the first time in 1923, it is believed. The idea is based on the method which according to tradition was employed by the Pharaoh Menes for dealing with the Nile in Egypt in ancient days and might therefore be called the " Pharaonic Project."

Its essential feature is that work is confined to one side of the river by making a bank of Nile Bank Section—say ten metres wide and 2 metres high—along the left of the Bahr el Gebel from Rejaf to Lake No and from Arediba to Lake No on the right bank of the Bahr el Ghazal. Such a bank would cut off over half(*) the present swamp area from contact with the Bahr el Gebel water. As the quantity of water entering the Bahr el Gebel is not changed and would be confined to less than half its original area the water levels would of course be higher and would therefore increase the swamp areas on the east towards the Bahr el Zeraf. The whole question of the value or uselessness of the proposal depends on whether this increase in swamp area on the east would be less than the decrease on the west. It is believed that the ground rises comparatively steeply towards the east and if this is so considerable benefit should accrue through the construction of the proposed bank. Suppose the nett saving in area of swamp, after allowing for the higher level, is only 25 per cent (the area shut off by the bank would be over 50 per cent of the present swamps and the figure 25 per cent allows for a 50 per cent extension of the swamp area on the east) then the mean annual saving of the evaporation loss is one quarter of the present swamp losses or about 3½ milliards at Malakal, the mean annual loss in the Swamps being about 14 milliards. Unfortunately in low years when Egypt wants extra water most the saving would be least, as the Swamp loss falls to about 4 or 5 milliards in such years, and the saving, or extra water supplied at Malakal, would only be about one milliard. Moreover a reservoir at Gebel Aulia or a greater capacity at Aswân would be a necessity to enable full advantage to be taken of the water saved, for much of the saving would take place in flood and if no reservoir existed in which to store it, it would be wasted to sea.

The information required to test the value of this proposal is a contoured plan round the boundaries of the Swamps. This is also required to investigate whether the use of Lake Albert Reservoir without a Sudd Channel is profitable, and with respect to the northern part, the Lake No swamps, to investigate the questions of flood escapes and remodelling of the White Nile and use of the Bahr el Gebel as a subsidiary channel.

Therefore even if the Pharaonic project is shown not to be feasible, no time or money has been wasted in investigating it, as the contoured plan made for the purpose is also required for the study of other projects.

A bank such as has been suggested would have a maximum length of about 900 kilometres, with a cube of about 25,000,000 cubic metres and allowing four piastres per cubic metre would cost L.E. 1,000,000. A dredging unit of one hydraulic and one dipper dredger would excavate about 500,000 cubic metres per annum, hence eight such units would do the work in about six years and if the bank were begun from the top end each year's work would provide some increase in swamp discharge. Moreover the amount of the annual increase could be measured with considerable accuracy for it is known from the formula :—

$$Y = 0{\cdot}174\,X + 236$$

in Chapter II, what the Malakal swamp spring discharge would have been for any given Mongalla flood discharge, had the bank not been made.

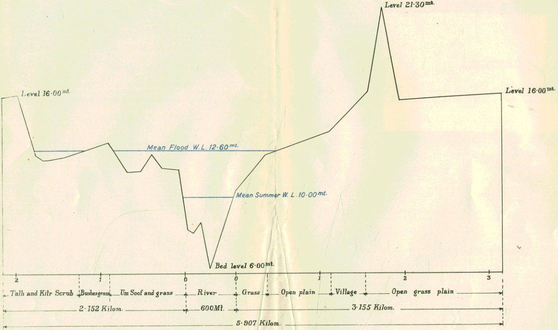
(*) Perhaps much more. See preface to third edition.

The work would not be entirely useless after the big project is completed, for the bank from Rejaf to Bor and from Lake No to Arediba would always be required, and these two sections form about one third of the total work.

This project seems to offer a speedy means of obtaining some not inconsiderable addition to Egypt's water supply at a comparatively small cost. There would be a steady increase in the Upper Nile discharge, some of it of course untimely and therefore useless till reservoirs are made to store it to a timely period, but a great deal of it could be used immediately for irrigation. The plant necessary would still have a large residual value at the end of the five or six years' work and could be used on the Sudd Channel proper while the experience gained in dredging under the peculiar conditions of the Upper Nile would be of the greatest value on the main project. If for an expenditure of about L.E. 1,000,000 a minimum of about one milliard cubic metres of water per annum can be secured for Egypt, the project that offers such possibilities seems at least worth investigation.

Government Press
11,670-1928-250 ex.

TYPICAL CROSS SECTION



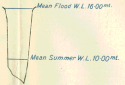
WHITE NILE NEAR RENK

475 KILOS. FROM KHARTOUM

Scales { Vertical = 1:100
Horizontal = 1:20 000

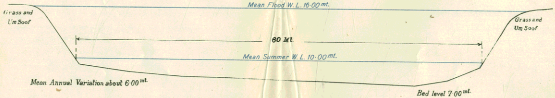
Fig 2.

TYPICAL CROSS SECTION



Scales {Vertical = 1:200, Horizontal = 1:5000}

Fig. 8 A



RIVER PIBOR NEAR ITS CONFLUENCE WITH R. BARO

Scales {Vertical = 1:200, Horizontal = 1:250}

Figs. 8 A and 8 B

TYPICAL CROSS SECTION



Scales { Vertical = 1:200
Horizontal = 1:5,000

Fig. 6 A



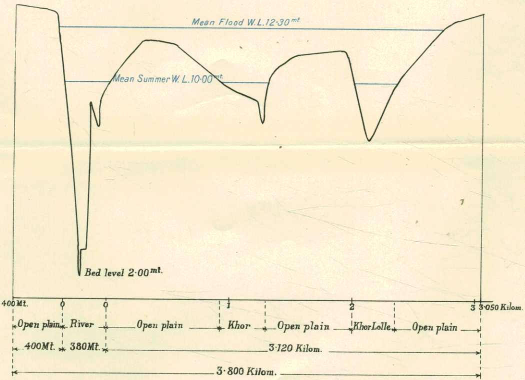
RIVER SOBAT NEAR THE MOUTH

Scales { Vertical = 1:200
Horizontal = 1:250

Figs 6 A and 6 B

SGFE 28/308

TYPICAL CROSS SECTION



WHITE NILE 849 KILOS. FROM KHARTOUM

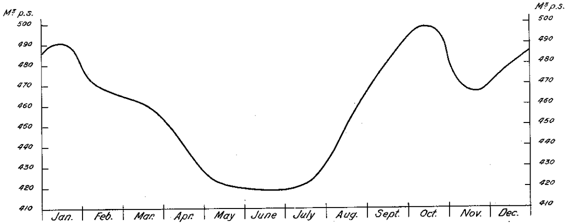
9 KILOS. UPSTREAM R. SOBAT MOUTH

Scales { Vertical = 1:100, Horizontal = 1:20·000 }

Fig 3.

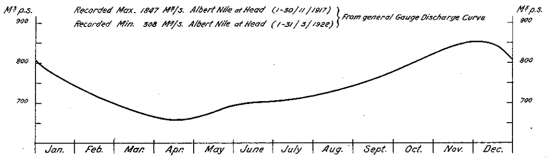
MONTHLY NORMALS

Recorded Max. 783 M³/s. (1-30/9/1918) } Malakal - Hillet Doleib
Recorded Min. 293 M³/s. (1-31/5/1922) }



Bahr el Gebel plus Bahr el Zeraf (1912-26)
at Malakal
Fig. 4

MONTHLY NORMALS



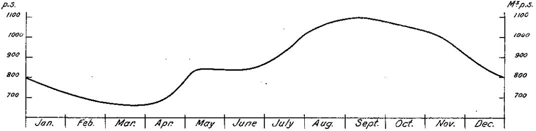
Albert Nile at Head (1912-26)

Fig. 1

S. of E. 28/308

MONTHLY NORMALS

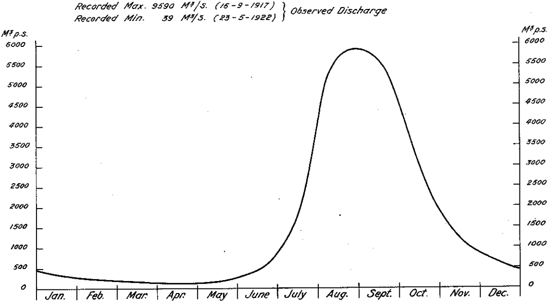
Recorded Max. 2830 M³/s. (1-10/10/1917) From general Gauge Discharge Curve.
Recorded Min. 298 M³/s. (14-3-1923) Observed Discharge.



Bahr el Gebel at Mongalla (1912 - 26)

Fig. 2

MONTHLY NORMALS

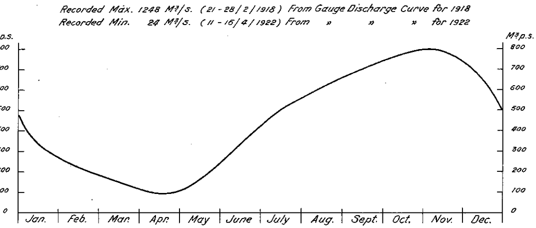


Blue Nile at confluence with White Nile (1912-26)

Khartoum

Fig. 8

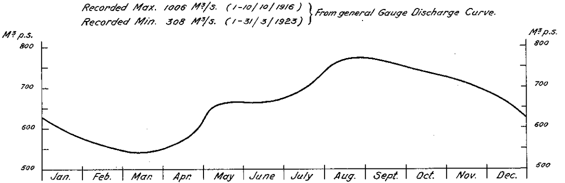
MONTHLY NORMALS



River Sobat at Mouth (Hillet Doleib) (1912 - 26)

Fig. 5

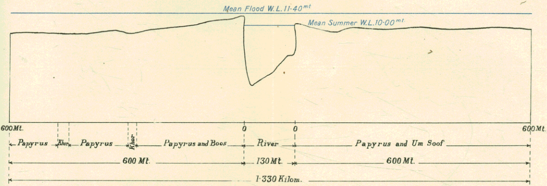
MONTHLY NORMALS



Bahr el Gebel at Bor (1912-26)

Fig. 3

TYPICAL CROSS SECTION



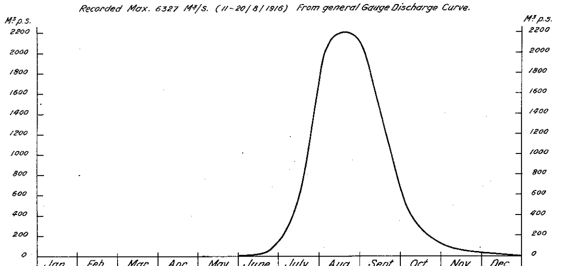
BAHR EL GEBEL IN PAPYRUS SWAMP

390 KILOS. FROM LAKE NO

Scales { Vertical = 1: 200; Horizontal = 1: 5,000

Fig 5.

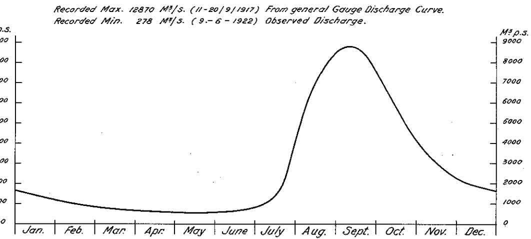
MONTHLY NORMALS



River Atbara at Mouth (1912-26)

Fig. 9

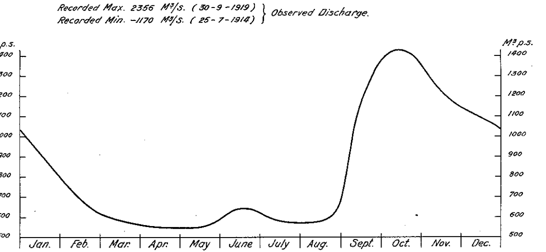
MONTHLY NORMALS



Main Nile at Halfa, above Aswan Reservoir (1912-26)

Fig. 10

MONTHLY NORMALS

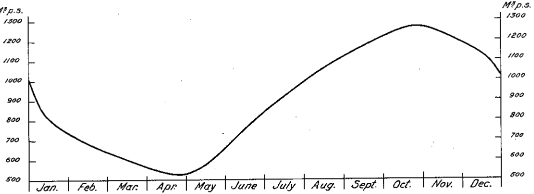


White Nile at confluence with Blue Nile (1912-26)
Moghren Khartoum

Fig. 7

MONTHLY NORMALS

Recorded Max. 1946 M³/sec. (1-20/3/1918) From gauge Discharge Curve.
Recorded Min. 320 M³/sec. (5-4-1922) Observed Discharge.

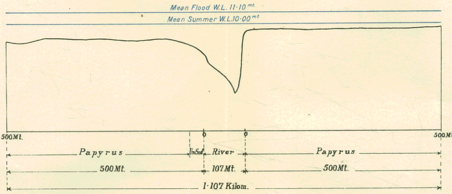


White Nile at Malakal (1912-26)

Fig. 6

S of E. 28/308

TYPICAL CROSS SECTION



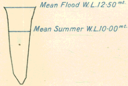
BAHR EL GEBEL IN PAPYRUS SWAMP

200 KILOS. FROM LAKE NO

Scales { Vertical = 1: 200
Horizontal = 1: 5,000 }

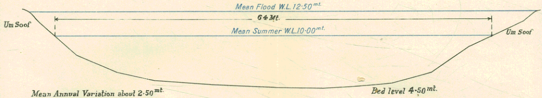
Fig 4

TYPICAL CROSS SECTION



Scales {Vertical = 1:200
Horizontal=1:5,000

Fig. 9 A



BAHR EL ZERAF NEAR ITS MOUTH

Scales {Vertical = 1:200
Horizontal =1:250

Figs. 9 A and 9 B